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COMPUTER B (NAS-NAS) COMMUNICATIONS SUPPORT.(U)

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Development Service
Washington, D.C. 20590

Computer B (NAS-NAS) Communications Support

Network Analysis Corporation
301 Tower Building
Vienna, VA 22180

July 1981

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

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16. Abstract

An analysis has been performed to determine the feasibility and desirability of incorporating into NADIN the message traffic currently serviced by the Computer B (NAS-NAS) Network. The use of NADIN to support NAS-NAS communications was found to be feasible and cost-effective. The most attractive approach to such support was found to be the enhancement of the NADIN architecture, using packet-switching technology, to provide virtual circuit and alternate routing capabilities between all NADIN backbone nodes. The results of this analysis are to serve as inputs to other tasks under this contract that will investigate a consolidated NADIN enhancement approach for supporting future FAA data communications requirements, including enhancements to support the replacement of FAA's enroute computer system, and the Remote Maintenance Monitoring System.

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METRIC CONVERSION FACTORS

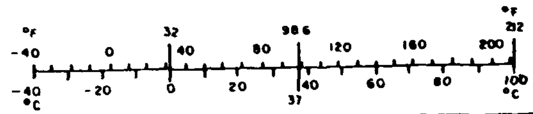
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The National Airspace Data Interchange Network (NADIN) is being developed, in its initial phases, as a common data communications network that will integrate various FAA communications services, specifically those involved in the exchange of information pertaining to air traffic control. The initial design was specifically directed to the absorption of the Aeronautical Fixed Telecommunication Network (AFTN), NASNET, and most of Service B. The design also provided for the expansion of NADIN facilities and circuits so as to accommodate growth, both in terms of requirements for included services and in terms of additional services.

Concurrently with efforts to implement the initial NADIN design, efforts have been directed to the analysis of other services that might be integrated into NADIN. These analyses have two major objectives. First they are to determine if the integration of the specific service into NADIN is cost/beneficial. Second, they are to determine the specific enhancements to NADIN that would be required to absorb that service. These efforts have already led to the specification of an enhanced NADIN, referred to as NADIN IA, which also includes communications support for the Flight Service Automation System (FSAS), Flight Data Input/Output (FDIO) equipment, Automated Flow Control (AFC) and the National Flight Data Center Information System (NFDC/IS). Current FAA plans call for the implementation of NADIN IA in 1983.

Studies of further possible enhancements are continuing. This report documents such an analysis conducted with respect to the Computer B (NAS-NAS) service.

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INTRODUCTION

1.1 SUMMARY OF RESULTS

Enhancement of the National Airspace Data Interchange Network (NADIN) to provide effective support for Computer B (NAS-NAS) communications is feasible and cost-effective. This is the major finding from the comparative analysis of alternative approaches to NAS-NAS communications support. This and other related findings have led to the following conclusions:

> **Conclusion 1:** NAS-NAS communications should be incorporated into NADIN before the NAS 9020 computers are replaced.

The architecture of the current Computer B (NAS-NAS) Network would have to be significantly altered in order to facilitate replacement of enroute computers (expected about 1988) and to support other planned modifications to the enroute computer system. In comparison, NADIN, which can be enhanced to meet NAS-NAS requirements, includes in its basic design features more compatable with the requirements of those long-range plans for computer system modification.

> **Conclusion 2:** If NADIN is to support NAS-NAS communications, the NADIN architecture should be enhanced so as to provide virtual circuits and alternate routing capabilities based on packet-switching technology.

This approach, although involving more modifications and greater cost than the other enhancements to NADIN considered, provides greater benefits, not just with respect to the NAS-NAS service, but also with respect to longer range plans for computer system modification and NADIN evolution.

Conclusion 3: Enhancements to the NADIN architecture to incorporate packet-switching technology should reflect a broader range of requirements than just those associated with the NAS-NAS service.

The suggested enhancements to the NADIN architecture will facilitate the support of a number of FAA communications requirements in addition to the NAS-NAS service. Greater efficiency would thus be achieved by implementing an integrated enhancements package, optimized to support as many of those requirements as practical. Since the NAS-NAS Network currently performs in a completely satisfactory manner, reasonable delays to develop and implement such an integrated enhancements package can be tolerated.

1.2 PURPOSE AND SCOPE

Under FAA Contract DOT-FA79WA-4355, Network Analysis Corporation (NAC) is investigating the feasibility and technical approaches for enhancing NADIN to incorporate a variety of communications services not included as part of the initial implementation. Results of earlier efforts under that contract have already been reflected in the specifications for the first enhancements to NADIN (NADIN IA).

Task 2 of the contract addressed the Computer B (NAS-NAS) service. It determined the most cost/beneficial approach to the support of NAS-NAS communications, considering the current Computer B (NAS-NAS) Network and various enhancements to NADIN IA. This report documents that study and its results.

In order to establish a baseline of costs and benefits that would result from including various services within NADIN, each service is being considered separately during the initial phases of the contract. Thus this task (Task 2) considered the possible enhancement of NADIN IA to incorporate the NAS-NAS service with minimal regard to other possible service additions. Further, it considers only subjectively the impact of the ATC Computer Replacement Program (CRP) and the Advanced Enroute Automation (AERA) Program. The results of Task 2 and other tasks related to individual communications services will, however, serve as major inputs for three broader tasks under the contract:

- Tasks 12 and 14, which address communications support for the Computer Replacement Program, and

- Task 13, which addresses the integration of the individual service requirements and proposed enhancements.

1.3 BACKGROUND

The National Airspace System (NAS) requires an intercenter computer communications subsystem for the fast, accurate and reliable exchange of flight plans and track data. This communications service is currently provided by the Computer B (NAS-NAS) Network. That network is a collection of point-to-point circuits between the NAS 9020 computer complexes located at neighboring Air Route Traffic Control Centers (ARTCCs).

The NAS-NAS Network performs in a highly acceptable manner, at a cost that is high but not unreasonable. Although this network should be able to provide high quality service indefinitely, broader FAA concerns suggest that it might be beneficial to provide the NAS-NAS service through a more flexible, common network, such as NADIN.

1.3.1 NAS-NAS Network Limitations

As suggestd above, there are no limitations associated with the performance of the NAS-NAS Network. The NAS-NAS service does, however, impact on other areas of FAA interest. These broader concerns reveal limitations in terms of cost, NAS 9020 communications overhead and interconnection flexibility.

1. Cost: The major concern of FAA is air safety. Cost must thus be a lessor concern when considering enhancements to the Air Traffic Control (ATC) System. Nevertheless, cost efficiency is always desirable, especially in light of the current tight government budget and the continuing cost increases for communications facilities.

   The current NAS-NAS Network employs dedicated, redundant communications links, with capacity far in excess of that required, even considering projected air traffic growth to the end of the decade. The annual cost of this service is currently about $500,000. Significant savings should be possible, without significant service degradation, through the sharing of communications resources.

2. NAS 9020 Communications Overhead: The NAS-NAS Network requires four NAS 9020 adaptor ports at each end of a link between two ARTCCs. As a result up to 28 such ports are required at one NAS 9020 complex just for the NAS-NAS service. In addition, the NAS-NAS Network requires that the NAS 9020

computers perform essentially all associated communications functions, functions that can generally be performed more efficiently by specialized communications equipment.

These requirements on 9020 resources are not excessive, even when considered in combination with similar requirements for other communications services terminating at the 9020 computer. However, the projected growth in air traffic together with the associated need to automate more ATC functions would strain the capacity and capabilities of the 9020 computers in the next decade. In light of this, FAA has initiated the ATC Computer Replacement Program, directed toward the replacement of the 9020s starting about 1988.

Possible reduction of NAS-NAS communications requirements on the 9020 would be beneficial from two aspects. First, any reduction in such requirements would increase the capacity of the 9020 for new functions prior to computer replacement. Second, at the time of computer replacement, switch-over and testing would be greatly facilitated if the number of individual interfaces to the computers were reduced.

Incorporation of the NAS-NAS service into a common network such as NADIN could significantly reduce the number of interfaces required. The potential would also exist to reduce the communications functions performed by the 9020. Utilizing this latter potential would require major modifications to the NAS 9020 software and should be avoided unless computer capacity becomes strained prior to replacement of the NAS 9020s. Use of a common network for NAS-NAS communications could thus serve as a near-term hedge and a longer range transition facilitator.

3. Interconnection Flexibility: Although the NAS-NAS Network has a highly connected topology, direct communications is only provided between designated ARTCCs, generally those that are adjacent. Any use of the network for indirect routing of messages requires the inclusion of switching functions in the 9020 software and places a greater processing load on the 9020 computer. This approach has been employed at selected ARTCCs to relay flight data from more remote ARTCCs to the Jacksonville computer complex, to aid in flow control.

NAS-NAS communications between centers that are not directly linked by the current network, although not currently required, will be required by the end of the decade. Following replacement of the NAS 9020s, a major program (AERA) to increase automation of enroute ATC functions is to be implemented. The degree of automation anticipated makes it essential that there be no significant break in automated functions, even if an entire center is lost (e.g., as a result of an earthquake). Various concepts are being studied by FAA to provide for such contingencies. These generally involve the use of the ATC computers at one or more neighboring centers to back up an inoperative ATC computer. Each ATC computer must thus be able to exchange NAS-NAS messages with the same computers as the one(s) it is designated to back up.

In order to provide such flexibility in the NAS-NAS Network, each ATC computer would have to act as a message switch or there would have to be a major increase in the number and miles of dedicated NAS-NAS links. A common network would not be so limited. NADIN, with its centralized switches and the ability of one switch to back up the other, already provides for inter-communications between all ATC computers. A less centralized topology would, however, serve this function more effectively.

1.3.2 NADIN Limitations

Use of NADIN to support NAS-NAS communications can overcome the above limitations of the NAS-NAS Network. Initial NADIN and its first enhancement (NADIN IA), although designed to provide high level performance, have limitations with respect to supporting the NAS-NAS service. These relate to network delays and back-up service.

1. Network Delays. The point-to-point, dedicated links of the NAS-NAS Network result in almost no network delay. Use of NADIN, on the other hand, would require NAS-NAS traffic to contend with other message traffic for use of the links. Additional delays are introduced by processing at the concentrators and switches. Although the specifications for initial NADIN and NADIN IA call for average end-to-end delays of less than two seconds, this is not felt to be

satisfactory for NAS-NAS traffic. Further enhancements to NADIN, such as increasing link capacities, providing dedicated virtual channels and/or providing special priorities for NAS-NAS messages, could reduce the network delays.

2. Back-Up Service. The current NAS-NAS Network provides redundant, full-duplex lines for each network link. Thus, if one line is lost, the other can provide the complete, undegraded service. Initial NADIN and NADIN IA provide a dial back-up system for use in the event of primary line outages. This back-up system, which uses the nationwide, commercial circuit-switched network, does not provide the same quality of service as that of the NAS-NAS Network. Specifically:

   - it requires longer to reestablish connections after a line outage; and

   - it does not provide link qualities equivalent to those of the primary leased lines.

1.4 STUDY APPROACH

In order to determine the most cost/beneficial approach for the support of NAS-NAS communications, a four step analysis methodology has been employed. These steps are identified below, including references to the more detailed presentations later in this report.

Step 1. Identification of the environment and requirements associated with NAS-NAS communications (Section 2).

Step 2. Identification of alternative approaches for enhancing NADIN to meet the NAS-NAS requirements (Section 3, with additional details provided in Appendices A, B and C).

Step 3. Analysis of the individual alternatives (Section 4).

Step 4. Comparative evaluation of the various alternatives (Section 5).

SECTION 2

COMMUNICATIONS ENVIRONMENT AND REQUIREMENTS

2.1 INTRODUCTION

As a first step in the analysis of approaches to support NAS-NAS communications, a requirements profile was developed. That profile has three major components:

Communications Environment: (Section 2.2) - This section presents an overview of current FAA flight data communications, emphasizing the NAS-NAS Network. A brief discussion of NADIN and its relationship to such communications is also included.

Strategic Requirements: (Section 2.3) - This section identifies the qualitative requirements that would apply to any communications utility being considered to serve the NAS-NAS functions. These requirements, which provide scope and direction to subsequent analyses, include objectives, policy and cost analysis procedures.

Tactical Requirements: (Section 2.4) - This section identifies the quantitative requirements that would apply to any communications utility being considered to serve the NAS-NAS functions. These requirements, which govern the development of design details, include connectivity, capacity and performance.

2.2 COMMUNICATIONS ENVIRONMENT

In order to control enroute IFR air traffic, FAA operates 20 ARTCCs within the counterminious U.S. (CONUS). These centers and the area each controls are indicated in Figure 2-1. Because of their key role in air traffic control, these centers are major nodes in a variety of FAA communications networks and, in particular, have been selected as communications concentrator locations for NADIN.

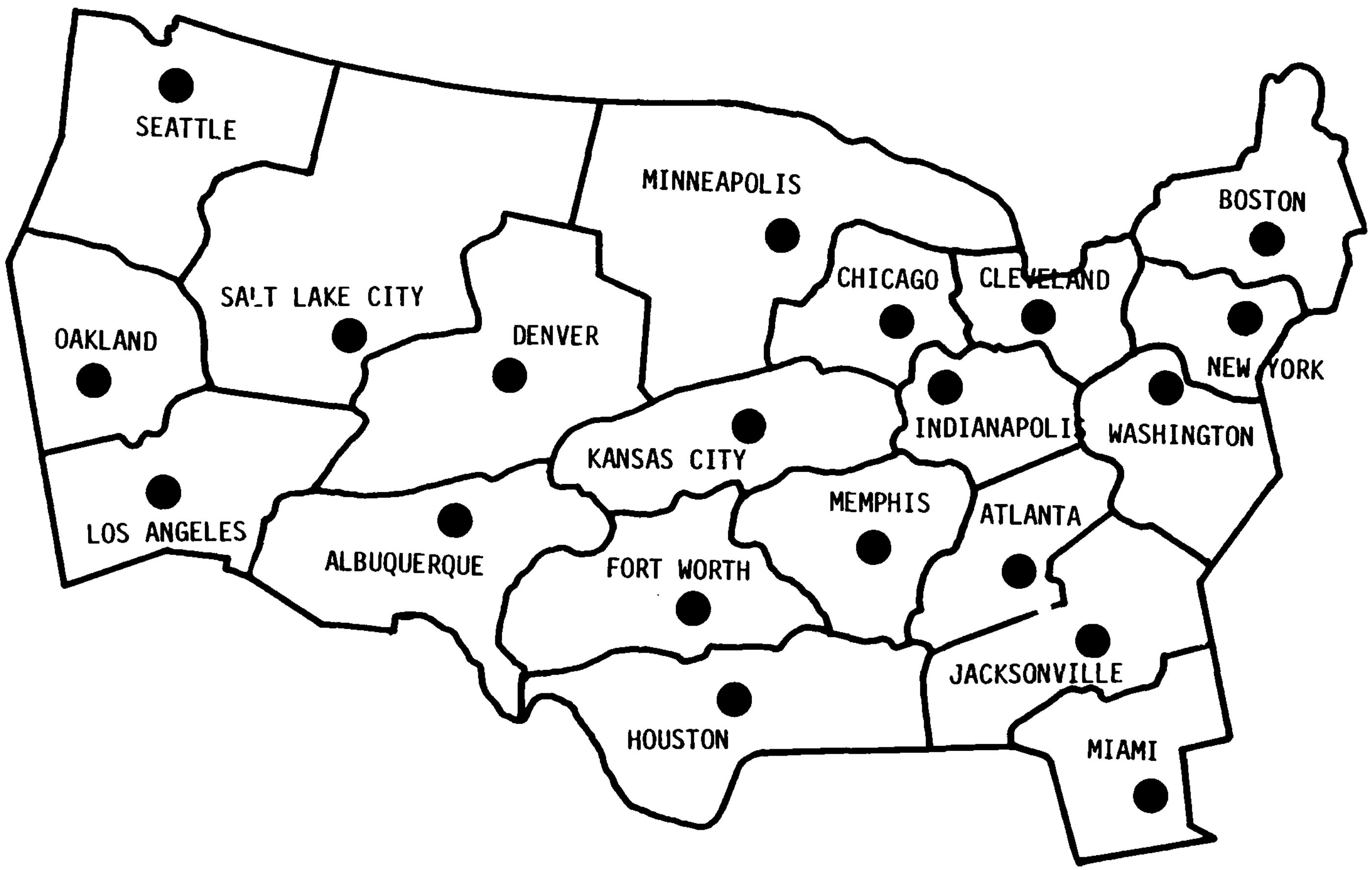


FIGURE 2-1: AIR ROUTE TRAFFIC CONTROL CENTERS

2.2.1 General Flight Data Communications

Effective air traffic control requires that timely information about planned and active IFR flights be made available to FAA controllers at the centers and at facilities in terminal areas which the flights use or overfly. Flight data are provided to the centers from a number of sources. These include:

- flight service stations, airline offices, military base operations (BASOPS) and non-U.S. centers and stations, which provide original flight plans and flight plan amendments,
- terminal areas, which provide flight plans and progress data,
- radars, which provide flight position and identification data, and
- neighboring ARTCCs, which provide flight plans and track data for flights crossing center boundaries.

The high volume of air traffic and the resulting high volume of flight data made it mandatory that the associated data processing functions be automated. For this purpose, FAA has installed a computer complex at each ARTCC. These complexes, using NAS 9020 computers (also referred to as the NAS En Route Stage A computers), process all flight related data received by the center and, at the appropriate time, pass pertinent data on to:

- enroute controllers at the ARTCCs,
- terminal area controllers and computers,
- the central flow control computer, and
- neighboring center computers.

2.2.2 Current Flight Data Networks

The NAS 9020 computers receive and disseminate flight data through a variety of communications networks and circuits (Reference 1). Many of these circuits are intra-center (i.e., they provide enroute controllers and other center personnel access to flight data) or provide direct computer input from remote radars. Of greater interest for this study are the networks and circuits connecting the NAS 9020s with facilities outside of the center. These are indicated in Figure 2-2 and are described briefly below.

The Area B/Supplemental B Networks connect the NAS 9020s with teletype terminals at flight service stations and non-U.S. centers and stations. These networks primarily provide for flight plan data entry to the computers. Computer outputs over these networks primarily include displays of previously entered data and messages related to input acceptance or rejection.

The Utility B Circuits connect the NAS 9020 computers to teletype terminals at airline offices and military BASOPS within the centers' control areas. These circuits serve a function similar to the Area B/Supplemental B Networks.

The Center B Network is primarily a teletype-to-teletype network interconnecting the ARTCCs and special FAA administrative and support facilities. The NAS 9020s are linked to this network to permit limited message transmission to the Central Flow Control Facility in Washington, D.C.

The FDEP Circuits interconnect the NAS 9020 computers with keyboards and flight strip printers at towers and approach control facilities in terminal areas. These circuits primariy provide for the exchange of flight plans and progress data between the terminal area controllers and the NAS 9020.

The Computer B (NAS-ARTS) Network interconnects each NAS 9020 computer complex with Automated Radar Terminal System (ARTS) computers located in the busier terminal areas. This network provides for the automatic exhange of flight plan and track data and facilitates the handoff of flights that cross terminal area boundaries.

The Computer B (NAS-NAS) Network interconnects the NAS 9020 computers at (generally) adjacent ARTCCs. This network provides for the automatic exchange of flight plan and track data for flights that cross center boundaries and facilitates the handoff of such flights. Portions of this network are also used as part of the Automated Flow Control (AFC) Store-and-Forward Network, discussed below.

The AFC Store-and-Forward Network connects the NAS 9020 computers with the Jacksonville Computer Complex (JCC). This network provides for the transfer of flight plans and progress data (on selected flights) from the ARTCCs to the JCC. It provides

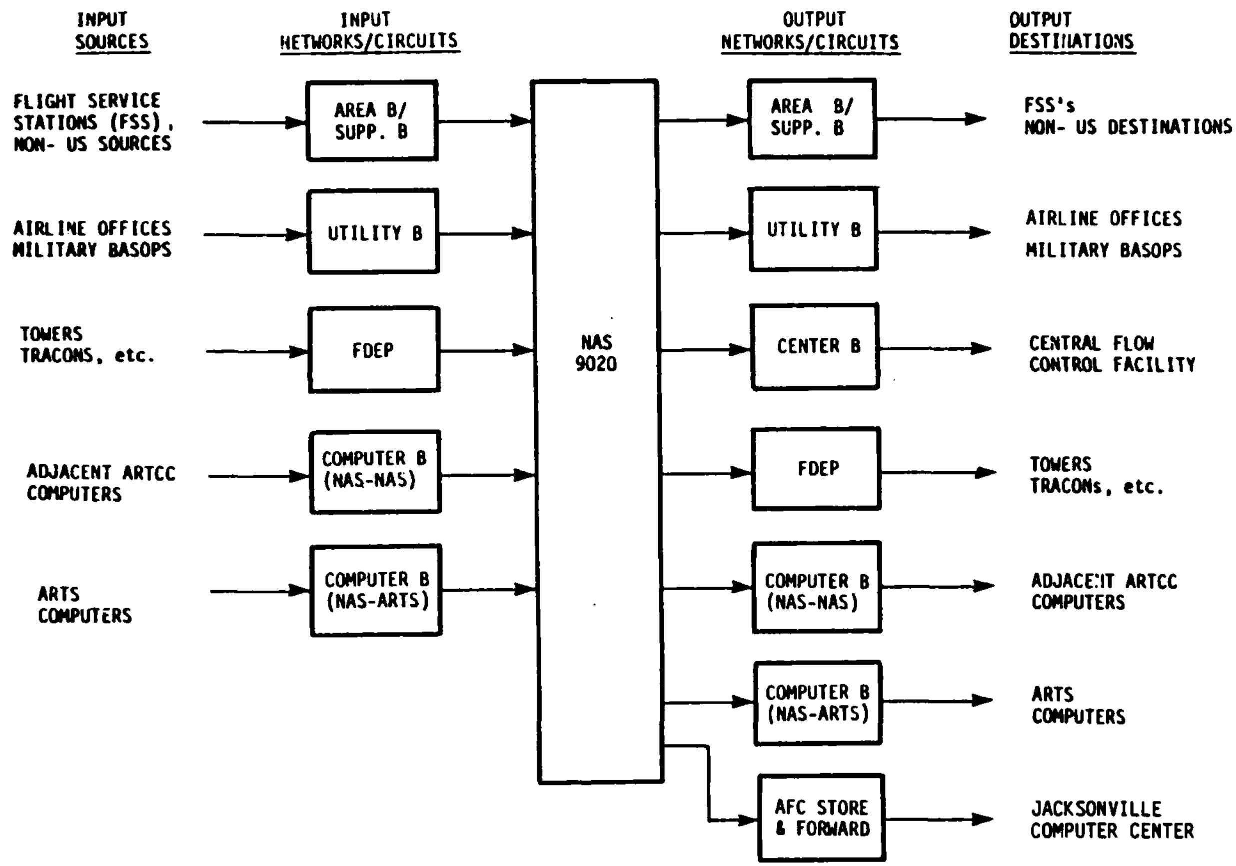


FIGURE 2-2: EXTERNAL COMPUTER COMMUNICATIONS (CURRENT)

direct connections between the JCC and the NAS 9020 computers at five ARTCCs, called Forwarding Centers. Messages from other ARTCCs are routed through the Forwarding Centers on a store-and-forward basis using specific NAS-NAS Network links.

2.2.3 The NAS-NAS Network

The current NAS-NAS Network is composed of 90 independent point-to-point communications links. The nodes of the network are the NAS 9020 computers at the 20 CONUS ARTCCs. The interconnectivity between these nodes is shown in Figure 2-3.

Each connection shown in Figure 2-3 actually represents two distinct communications links. This is illustrated in Figure 2-4. Between every pair of interconnected 9020s there are two 2400 bit per second (b/s) full duplex lines, each primarily responsible for carrying message traffic in one direction. Should one of the two lines fail, the full duplex capability of the other is used to handle all the traffic. Should both lines fail, messages are automatically routed to a printer at the sending center. Supervisory personnel are then responsible for transmitting the messages to the destination center by teletype or voice communications.

The lines are interfaced with the 9020s through modems, which are directly connected to Interfacility Input (INTI) and Interfacility Output (INTO) Adaptors in the Peripheral Adaptor Modules (PAM) of the 9020s. Although not shown in Figure 2-4, each modem is connected to two INTI and two INTO adaptors on separate PAMs, in order to insure high availability. (Detailed discussion of the interface is contained in References 2 and 3). Data transferred through the INTI/INTO adaptors must use 9 bit (8 data bits plus 1 parity bit) characters. The bits are transmitted serially.

The NAS-NAS Network is used to transmit 13 types of messages (ignoring AFC store-and-forward messages) between the 9020s. These are discussed briefly below, in terms of four message categories. (Detailed discussion of each message type is provided in References 4 and 5.)

2.2.3.1 Flight-Data Messages

Prior to the time that an IFR flight is expected to cross the boundary between two ARTCCs, the currently controlling center (sending center) must transmit the associated flight plan data to the center that is to have control following the boundary crossing (receiving center). Such data is transmitted through four types of messages:

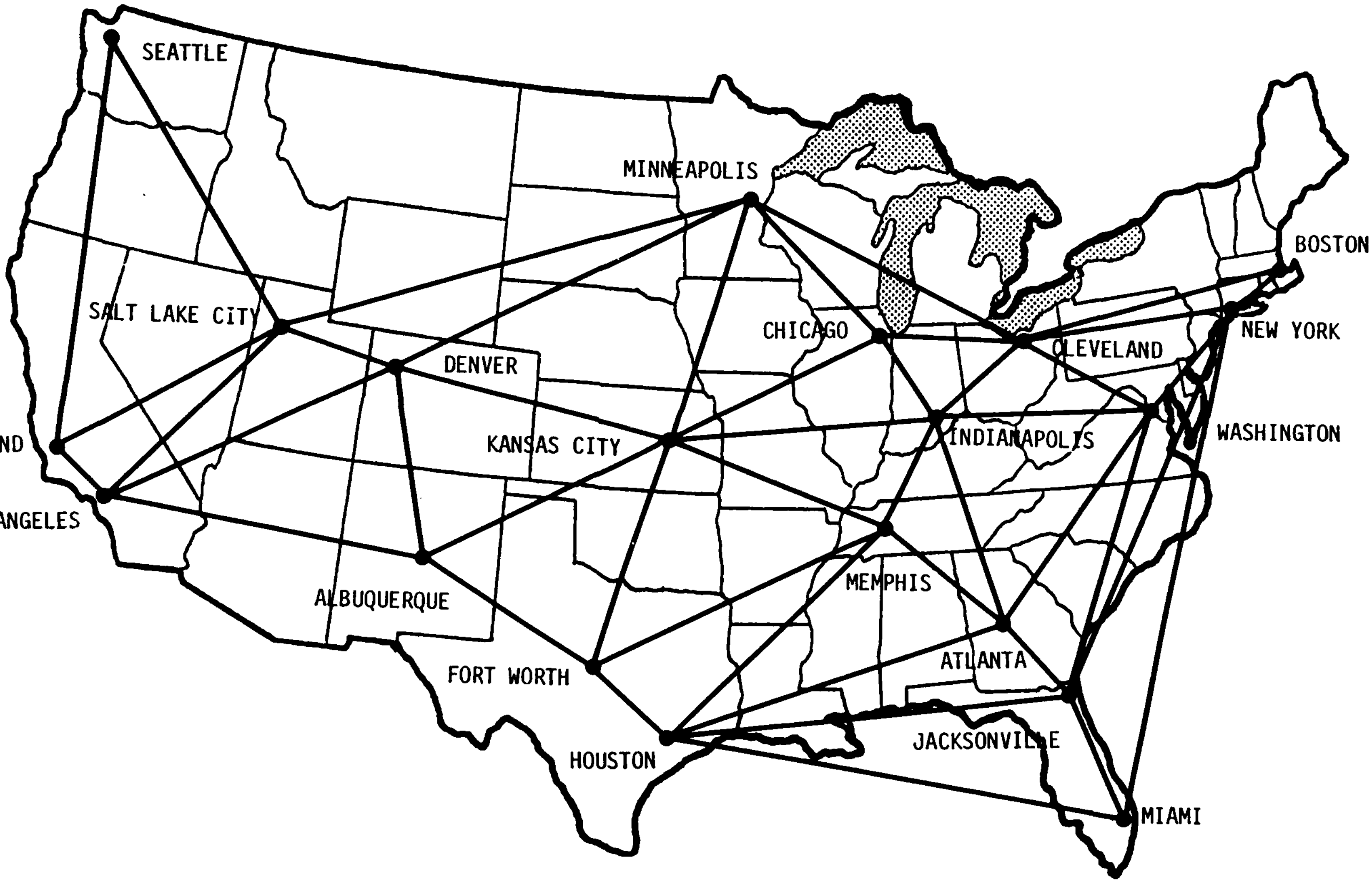


FIGURE 2-3: CURRENT COMPUTER B (NAS-NAS) NETWORK

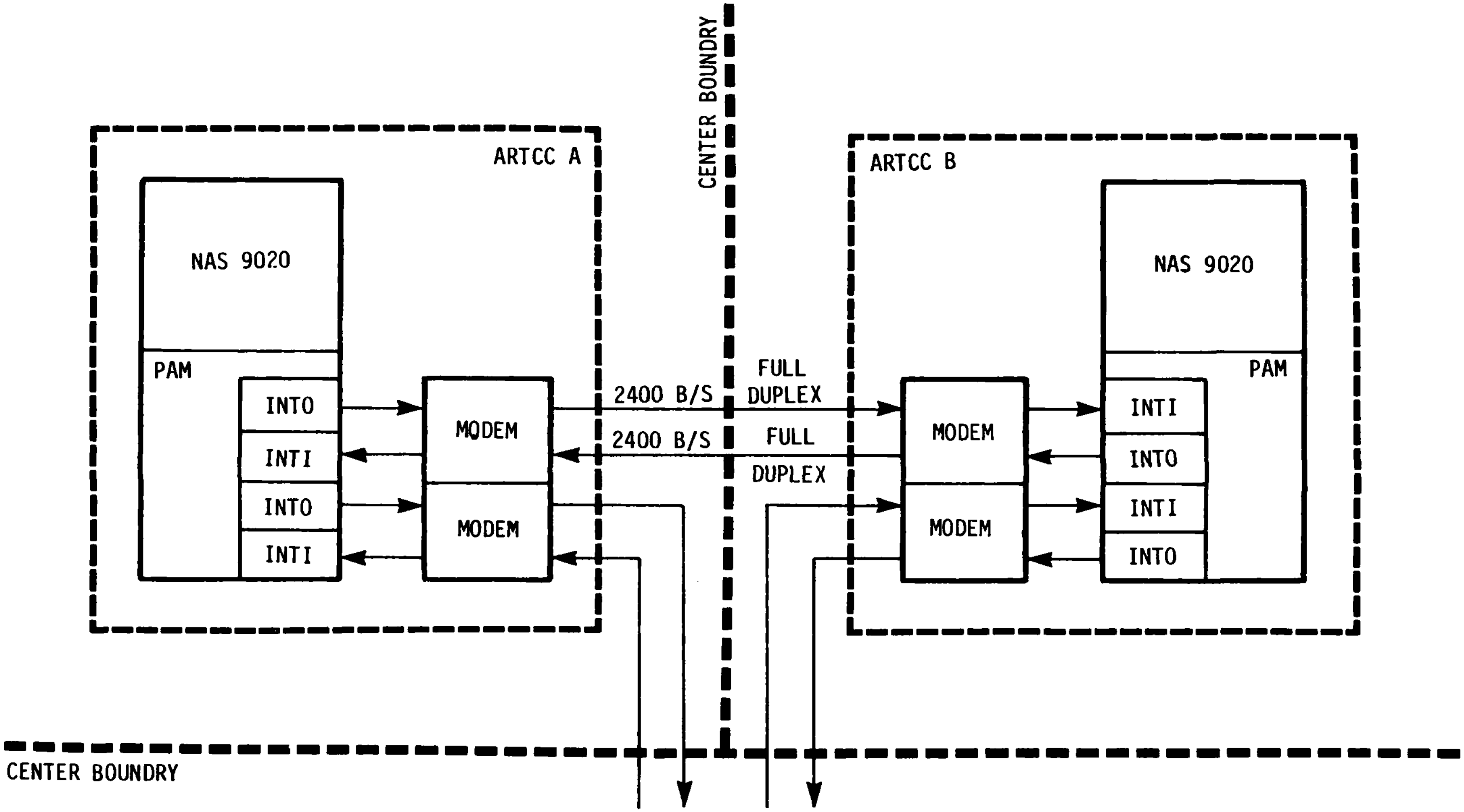


FIGURE 2-4: NAS-NAS NETWORK PHYSICAL CONNECTIONS

Flight Plans (FP) - the current flight plan as stored by the sending center,

Amendment Messages (AM) - updates to a flight plan previously transmitted,

Remove Strip Messages (RS) - instructions to the receiving center to delete all previously transmitted flight plan data for specific flights, and

Hold Messages (HM) - notifications to the receiving center that flights for which data were previously transmitted are in an indefinite hold status.

2.2.3.2 Track-Data Messages

As boundary crossing becomes imminent, flights will be handed off through a series of track-data messages. Three types of messages are used:

Initiate Transfer Messages (TI) - notification from the sending to receiving center that the hand-off process is beginning,

Track Update Messages (TU) - updates of flight velocity and coordinates for flights in hand-off status, transmitted from the sending to receiving center, and

Accept Transfer Messages (TA) - notification to the sending center that the receiving center has accepted a handoff, or notification to the receiving center that the sending center is taking the flight out of hand-off status.

2.2.3.3 Response Messages

Whenever a NAS 9020 receives a flight-data or track-data message, other than a TU, it automatically responds with one of three messages:

Accept Message (DA) - indicator that a valid message with no errors was received,

Request Retransmission Message (DX) - instruction to retransmit a message that was received with transmission errors, and

Reject Message (DR) - notification that an unacceptable message was received.

2.2.3.4 Miscellaneous Messages

Other messages are also transmitted infrequently between the 9020 computers. These include:

- General Information Messages (GI),
- Test Messages (TR), and
- Center Operational Messages.

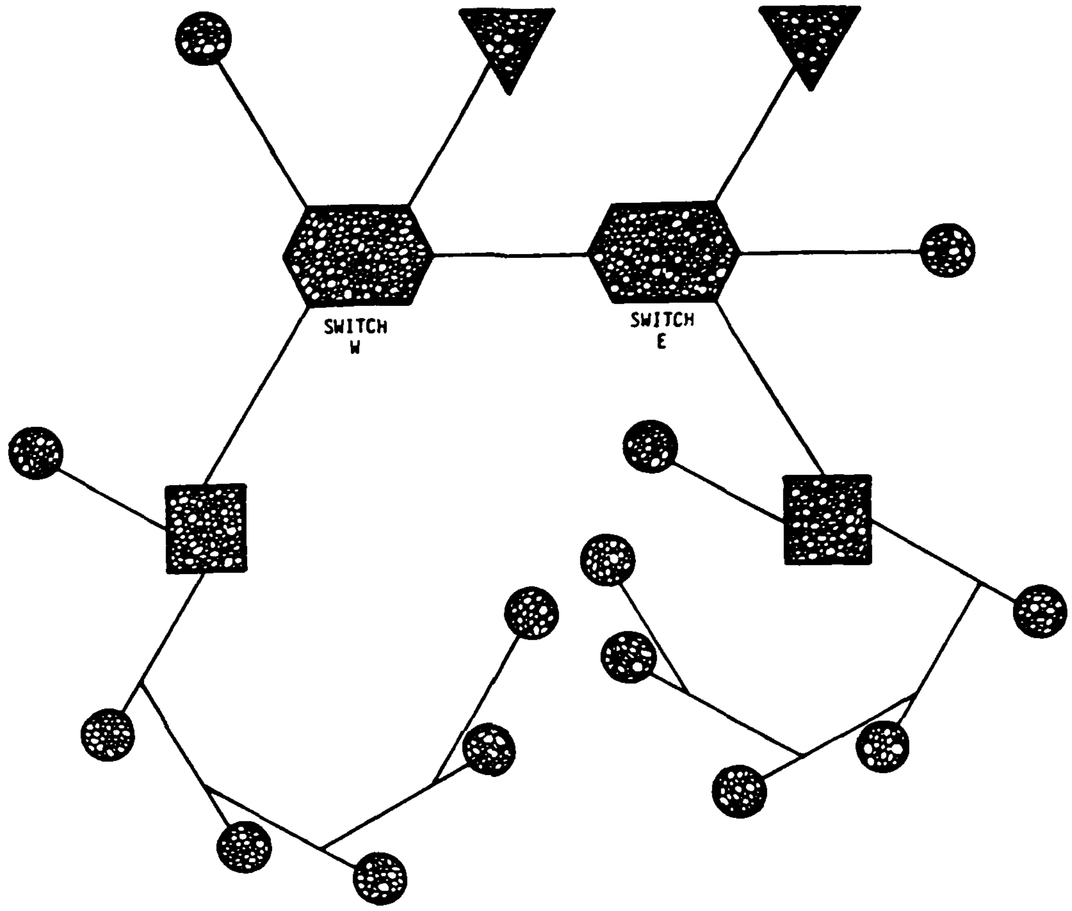
2.2.4 NADIN

NADIN (Reference 6) is being developed as a common data communications network to integrate many of the currently separate FAA communications networks and to facilitate the addition of new FAA communications services. Figure 2-5 illustrates the basic elements of the initial NADIN implementation.

NADIN concentrators will be located at each of the 20 CONUS ARTCCs plus Anchorage, Honolulu and San Juan. Each concentrator is directly connected to one of two NADIN switches (backup connection to the second switch is also provided). The switches and concentrators are further connected to a variety of computers and data terminals which constitute the origins and destinations of the messages handled. In particular, each NADIN concentrator will be directly connected to the collocated 9020 complex.

Initial implementation of NADIN (expected by early 1983) will direct all messages to a NADIN switch. The switch will administratively process the messages and route them to the desired destinations. Among the services to be included as part of the initial implementation are Area B/Supplemental B, Utility B and Center B. The FDEP service, as upgraded under the FDIO program, and the AFC Store-and-Forward service are also expected to be incorporated at the time of or shortly after initial implementation. Thus, the external NAS 9020 communications by late 1983 should appear as shown in Figure 2-6.

A variety of enhancements are being considered for NADIN. Thus, to more efficiently accommodate the FDEP/FDIO service, local switching at the NADIN concentrators (Reference 7) is to be provided as part of the first NADIN enhancement (NADIN IA). This feature will have the concentrator (rather than the NADIN switch) route pertinent classes



LEGEND:

SWITHES - 2; E-ATLANTA, W-SALT LAKE CITY

CONCENTRATORS - 23; ONE AT EACH ARTCC AND ANCHORAGE, HONOLULU, AND SAN JUAN

TERMINALS - UP TO ABOUT 50 PER CONCENTRATOR THROUGHOUT EACH ARTCC AREA, PLUS SOME AT SWITCHES. SOME ON DEDICATED CIRCUITS, MOST ON MULTIPOINT

EXTERNAL SYSTEMS AND NETWORKS, E.G., INTERNATIONAL AFTN, WMSC

FIGURE 2-5: NADIN I SCHEMATIC

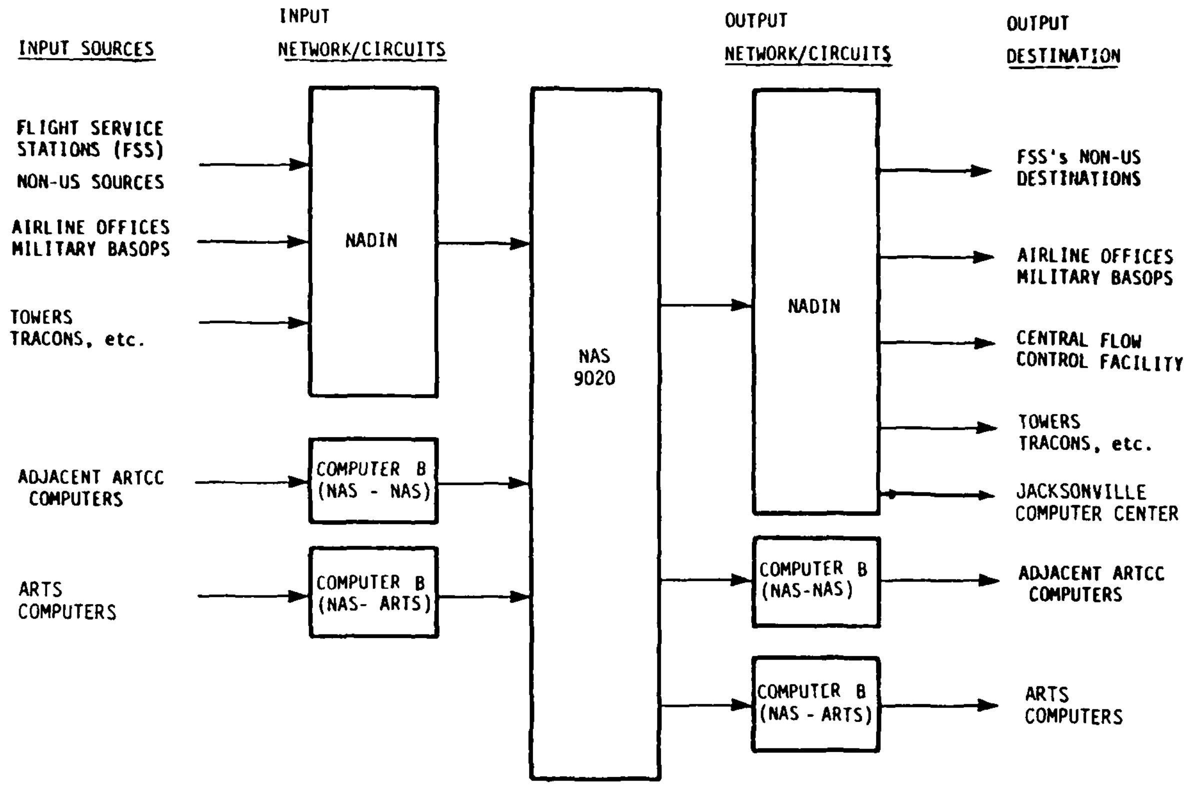


FIGURE 2-6: EXTERNAL COMPUTER COMMUNICATIONS (NADIN 1983)

of messages whose origins and destinations are both within the area controlled by the associated ARTCC (this is the case for FDEP messages). Another possible enhancement involves direct connections between selected concentrators, thereby providing alternate routing capabilities. This feature would appear to offer benefits if the NAS-NAS service were incorporated i: to NADIN.

2.3 STRATEGIC REQUIREMENTS

A communications utility must meet the folowing strategic requirements in order to be considered an acceptable alternative for handling the NAS-NAS traffic.

2.3.1 Objectives

The NAS-NAS utility must satisfactorily perform the current functions of the NAS-NAS Network (other than those associated with the Network's interim role as part of the AFC Store-and-Forward Network). Since the current NAS-NAS Network is satisfactory and since the NAS 9020 computer system is due to be replaced around 1990, a utility to replace the current network must perform the NAS-NAS functions at a total cost no greater than the current network, and with minimal changes to the computer system.

The requirement for minimal change leads to many of the tactical requirements presented later. At the strategic level, this requirement implies:

- the NAS-NAS utility must require no changes to the NAS 9020 software, other than minor modifications to accommodate a new interface, and

- the utility must be transparent to enroute controllers, thus avoiding the need for special training (i.e., it must introduce no new or altered controller activities, nor modify the displays received by the controllers).

2.3.2 Policy

The utility must be consistent with FAA Order 1830.2 (Reference 8). That order identifies sets of standards related to communications codes, signalling rates, transmission

modes, bit sequencing, character structure, link control procedures, message transfer and electrical and physical interfaces to be implemented as part of new or upgraded FAA data communications systems.

2.3.3 Cost Estimation

As indicated earlier, the NAS-NAS utility must cost no more than the current NAS-NAS Network. Cost comparisons must reflect the following, in addition to standard considerations.

- Comparisons must be based on life-cycle costs; i.e., they must appropriately combine one-time and recurring costs.

- Comparisons must be based on differences in cost to the total FAA program. Thus, since NADIN concentrators and switches will be purchased regardless of NAS-NAS utility selected, their costs need not be considered. Similarly, when a utility based on NADIN is considered, only the incremental costs of enhancing NADIN must be included. For such considerations it will be assumed that NADIN IA (Reference 9) is to be funded and implemented by 1983, regardless of any decision concerning the NAS-NAS utility.

2.4 TACTICAL REQUIREMENTS

A communications utility must meet the following tactical requirements in order to be considered an acceptable alternative for handling the NAS-NAS traffic.

2.4.1 System Configuration

The nodes of the NAS-NAS communications service are the NAS 9020 computer complexes at the 20 CONUS ARTCCs. In general, each center must have connectivity with every other center sharing a common boundary. In addition, since some flights using overwater routes bypass intervening ARTCC air space, connectivity is required between:

- New York and Jacksonville

- New York and Miami

- Miami and Houston

No connectivity is required between Houston and Albuquerque, since no air lanes cross the short common boundary between those centers.

The required connectivity is indicated by the current two-way Computer B (NAS-NAS) Network links, shown earlier in Figure 2-3. The direct connectivity provided by the current network is, however, not necessarily required.

2.4.2 Message Traffic

The NAS-NAS message traffic that must be handled by the utility is the current NAS-NAS traffic (ignoring AFC store-and-forward traffic) and its projections to CY 1988 (the year the NAS 9020 replacement is to begin). The best "current" message traffic data available are those developed as part of the 1976 study of the impact of AFC store-and-forward traffic on the NAS-NAS Network (Reference 10). Those data were obtained from detailed analysis of System Analysis Recording (SAR) tapes provided from all 20 ARTCCs. The ARTCCs were requested by letter (Reference 11), dated December 23, 1975, to provide tapes "of at least 20 minutes duration selected from each ARTCC's peak traffic hour for any convenient week since November 15, 1975."

The 1976 study identified eight message types that constituted over 99 percent of the NAS-NAS peak-period message traffic. These are:

TI - initiate transfer
TU - track update
TA - accept transfer
FP - flight plan
AM - amendment messages
RS - remove strip
DA - data accept
DR - data reject

The only change anticipated in the message traffic for the 1983-88 time frame is the traffic volume. The message types, their relative frequencies and their lengths are expected to remain unchanged.

2.4.2.1 Message Lengths

Analysis of the SAR tapes for the 1976 study produced the NAS-NAS message length data shown in Table 2-1 These data require no adjustment for use in this study.

2.4.2.2 Message Traffic Volumes

Analysis of the SAR tapes for the 1976 study produced the NAS-NAS message traffic volumes (in messages per hour) for individual links shown in Table 2-2. As indicated earlier, the specific nodes and the interconnectivity requirements are not expected to change for the 1983-88 time frame. Only the traffic volumes shown are expected to change. These should grow in proportion to the growth in IFR air traffic that crosses center boundaries.

An estimate of the growth rate has been obtained from FAA forecasts of IFR aircraft handled by the individual centers (Reference 12). Selected data from that source are shown in Table 2-3. Implied growth factors, relative to the 1976 data are shown in Table 2-4.

In order to obtain a conservative estimate of message traffic growth, the maximum growth factors (1.8 for 1983, 2.2 for 1988) have been used. The results of applying these factors to the 1976 traffic volumes are shown in Table 2-5 (for 1983) and 2-6 (for 1988).

2.4.3 Transmission Delays

All flight-data and track-data messages must be transmitted and (except for TU messages) responded to without undue delay. Internal NAS 9020 delays in responding to such messages must average no more than 2 secoinds, and must be less than 4 seconds, 90 percent of the time (Reference 13). Delays due to message queueing and actual (one-way transmission of the data and response messages must average no more than 1 second, and must be less than 2 seconds 90 percent of the time. These requirements are summarized in Table 2-7.

Message Type	Relative Frequency	Message Lengths (characters)			Coeff. of Var.
		Average	Maximum	Minimum	
TI	.082	44.2	49	38	.10
TU	.367	33.8	88	28	.25
TA	.077	25.4	30	22	.08
FP	.092	79.1	372	52	.34
AM	.062	55.8	254	29	.45
RS	.002	26.5	30	25	.09
DA	.310	28.1	36	23	.24
DR	.007	23.9	32	19	.56
ALL	1.000	37.7	372	19	.54

Notes:

Coefficient of Variation = Sample Standard Deviation/Average Length.
Message Length includes all current overhead characters.

Source: FAA-RD-76, Automated Flow Control Interim Communications, August, 1976.

TABLE 2-1: NAS-NAS MESSAGE LENGTH DISTRIBUTIONS

FROM: \ TO:	Albuquerque	Atlanta	Boston	Chicago	Cleveland	Denver	Ft. Worth	Houston	Indianapolis	Jacksonville	Kansas City	Los Angeles	Memphis	Miami	Minneapolis	New York	Oakland	Salt Lake City	Seattle	Washington
Albuquerque						107	285				224	298								
Atlanta								61	332	853			474							440
Boston					30											370				
Chicago					613				409		201				494					
Cleveland			30	570					519						9	302				448
Denver	144										83	282			358			386		
Ft. Worth	226							370			135		317							
Houston		125					435			117			131	4						
Indianapolis		366		564	469						169		227							258
Jacksonville		674						93						829		4*				363
Kansas City	90			347		86	100		251				240		110					
Los Angeles	547					276											608	69		
Memphis		325					263	130	187		181									
Miami								4		1060						62				
Minneapolis				416	9	293					75							28		
New York			425		745					4*				62						957
Oakland												406						187	281	
Salt Lake City						293						110			28		165		143	
Seattle																	233	116		
Washington		359			147				421	415						641				

*No traffic on these links during peak period from which data were obtained; The value shown has been arbitrarily used for the analysis.

Source: FAA-RD-76, Automated Flow Control Interim Communications, August, 1976

TABLE 2-2: NAS-NAS TRAFFIC MATRIX (1976) - PEAK PERIOD MESSAGES PER HOUR

Center	IFR AIRCRAFT HANDLED (thousands) 1976 (Act.)	1983 (Est.)	1988 (Est.)
Albuquerque	845	1,183	1,384
Atlanta	1,400	1,989	2,365
Boston	912	1,228	1,456
Chicago	1,851	2,643	3,276
Cleveland	1,652	2,524	3,155
Denver	722	1,149	1,380
Fort Worth	1,323	1,984	2,459
Houston	1,172	1,842	2,272
Indianapolis	1,336	2,006	2,484
Jacksonville	1,105	1,610	1,836
Kansas City	1,080	1,656	1,966
Los Angeles	1,091	1,624	1,868
Memphis	1,151	1,732	2,115
Miami	1,039	1,686	1,998
Minneapolis	1,003	1,600	1,970
New York	1,499	2,180	2,578
Oakland	952	1,384	1,645
Salt Lake City	462	783	923
Seattle	695	1,234	1,540
Washington	1,396	1,995	2,434
TOTAL	22,686	34,032	41,104

Source: FAA-AVP-79-1, IFR Aircraft Handled, forecast by Air Route Traffic Control Center, Fiscal Years 1979-1990, April, 1979.

TABLE 2-3: ANNUAL IFR AIRCRAFT HANDLED BY CENTER

	GROWTH FACTOR*	
	1983	1988
20-Center Average	1.5	1.8
Maximum (Seattle)	1.8	2.2
Minimum (Boston)	1.3	1.6
Busiest Center (Chicago)	1.4	1.8
Least Busy Center (Salt Lake City)	1.7	2.0

*Ratio of IFR Aircraft Handled for indicated year to IFR Aircraft Handled in 1976.

TABLE 2-4: RELATIVE GROWTH OF IFR AIR TRAFFIC

FROM: \ TO:	Albuquerque	Atlanta	Boston	Chicago	Cleveland	Denver	Ft. Worth	Houston	Indianapolis	Jacksonville	Kansas City	Los Angeles	Memphis	Miami	Minneapolis	New York	Oakland	Salt Lake City	Seattle	Washington
Albuquerque						193	513				402	536								
Atlanta								110	598	1535			853							792
Boston					54											666				
Chicago					1103				736		362				889					
Cleveland			54	1026					934						16	544				806
Denver	259										149	508			644			695		
Ft. Worth	407							666			243		571							
Houston		225					783			211			236	7						
Indianapolis		659		1015	844						304		409							464
Jacksonville		1213						167						1492		7				653
Kansas City	162			625		155	180		452				432		198					
Los Angeles	985					497											1094	124		
Memphis		585					473	234	337		326									
Miami								7		1908						112				
Minneapolis				749	16	527					135							50		
New York			765		1341					7				112						1723
Oakland												731						337	506	
Salt Lake City						527						198			50		297		257	
Seattle																	419	209		
Washington		646			265				758	747						1154				

TABLE 2-5: NAS-NAS TRAFFIC MATRIX (1983) - PEAK PERIOD MESSAGES PER HOUR

FROM: \ TO:	Albuquerque	Atlanta	Boston	Chicago	Cleveland	Denver	Ft. Worth	Houston	Indianapolis	Jacksonville	Kansas City	Los Angeles	Memphis	Miami	Minneapolis	New York	Oakland	Salt Lake City	Seattle	Washington
Albuquerque						235	627				493	656								
Atlanta								134	730	1877			1043							968
Boston					66											814				
Chicago					1349				900		442				1087					
Cleveland			66	1254					1142						20	664				986
Denver	317										183	620			788			849		
Ft. Worth	497							814			297		697							
Houston		275					957			257			288	9						
Indianapolis		805		1241	1032						372		499							568
Jacksonville		1483						205						1824		9				799
Kansas City	198			763		189	220		552				528		242					
Los Angeles	1203					607											1338	152		
Memphis		715					579	286	411		398									
Miami								9		2332						136				
Minneapolis				915	20	645					165							62		
New York			935		1639					9				136						2105
Oakland												893						411	618	
Salt Lake City						645						242			62		363		315	
Seattle																	513	255		
Washington		790			323				926	913						1410				

TABLE 2-6: NAS-NAS TRAFFIC MATRIX (1988) - PEAK PERIOD MESSAGES PER HOUR

ACTIVITY	DELAY TIMES (seconds) MEAN	90 PERCENTILE
NAS-NAS Message Transmission (FP, AM, RS, HM, TI, TU, TA)	1	2
NAS 9020 Response Processing	2	4
NAS-NAS Response Transmission (DA, DX, DR)	1	2

TABLE 2-7: ACCEPTABLE DELAYS FOR NAS-NAS TRAFFIC

2.4.4 Availability/Reliability

The NAS-NAS service must be operational seven days a week. Between any two centers, the utility must be operational during the hours when both centers are to be operational. This will be a maximum of 24 hours a day.

Utility outages cannot be completely avoided. The importance of the NAS-NAS message traffic thus requires a back-up service. Currently, this is provided by redundancy and through off-line printing of messages for transmission over intercenter teletype or voice circuits. The latter type operations cannot be tolerated too frequently or for too long a period. The NAS-NAS utility must thus meet the following reliability requirements:

- Mean Time Between Failures (MTBF) - greater than 1000 operational hours (less frequently than once per month).

- Mean Time to Repair, Replace or Bypass (MTTR) - 15 minutes or less.

SECTION 3

IDENTIFICATION OF ALTERNATIVES

3.1 INTRODUCTION

Five alternatives for supporting NAS-NAS communications have been analyzed. The first, Alternative 1, is the current NAS-NAS Network. Three involve the enhancement of NADIN to completely take over the NAS-NAS service. One involves the combined use of the current NAS-NAS Network and NADIN.

The four alternatives involving NADIN have been specifically tailored to overcome one or more of the limitations identified earlier. Thus:

- Alternative 2, Enhanced NADIN IA, includes increased capacities on selected links to assure acceptable NAS-NAS message delays.

- Alternative 3, Enhanced NADIN Architecture, provides for increased connectivity among NADIN nodes and packet switching among those nodes, to reduce network delays and minimize the need for a separate back-up system.

- Alternative 4, NAS-NAS/NADIN IA, eliminates the redundant NAS-NAS Network lines, using NADIN IA as a back-up in the event of line outage, thus reducing the NAS-NAS Network cost and facilitating full transition to NADIN at a later time.

- Alternative 5, Redundant NADIN IA, is essentially Alternative 2, with one extra (9,600 b/s) line on each backbone link, to increase availability and thus decrease reliance on a dial back-up system.

One of the major considerations in defining the NADIN alternatives was to assure that NAS-NAS message delay constraints would be met. As a general rule, such assurance can be achieved by providing special handling for NAS-NAS messages, e.g.:

- Under Alternative 2, NAS-NAS messages could be assigned higher priorities than other ATC messages, thus minimizing the queueing delays at the network nodes; and

- under Alternative 3, permanent virtual circuits could be established for NAS-NAS messages, thus reducing node processing delays.

Although such approaches are valid and should be investigated further, they were not used in the detailed analyses of this study. Rather, acceptable delays were assured by increasing the capacity of selected network links. This approach was felt to be most appropriate at this time for the following reasons:

1. It is not clear that any class of ATC messages should be given special handling relative to other classes of ATC messages.

2. Providing special handling for NAS-NAS messages can be expected to increase the network delays for other NADIN traffic. A broader study would be required to investigate network adjustments needed to meet the delay constraints for the other traffic, if NAS-NAS messages were given special treatment.

3. The approach used, i.e., increasing link capacities, represents a conservative approach, both in terms of cost and technology.

4. Even with the approach used, it was possible to demonstrate the feasibility and cost-effectiveness of NADIN support for NAS-NAS communications.

Each of the five alternatives is defined and described in the subsections below. Each is analyzed separately in Section 4.

3.2 ALTERNATIVE 1, THE CURRENT NAS-NAS NETWORK

The first alternative considered for the support of NAS-NAS requirements is the continued use of the current, independent NAS-NAS Network. That network has been described in Section 2. Of particular interest for this analysis are the following features of the network (see Figure 3-1):

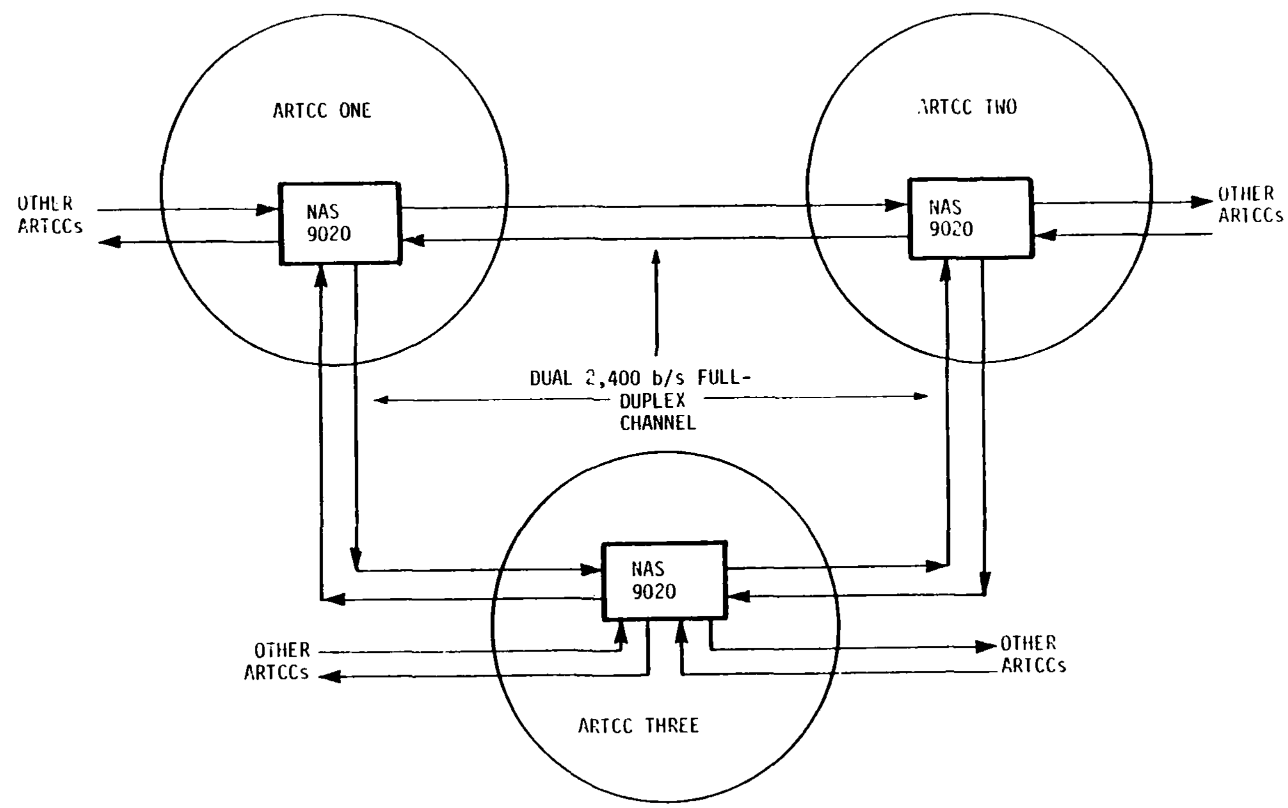


FIGURE 3-1: TYPICAL NAS-NAS MESSAGE PATHS, ALTERNATIVE 1

- The network provides a direct, redundant connection between every pair of NAS-9020 computer complexes that exchange NAS-NAS messages.

- Each link consists of two full-duplex, voice-grade channels, each operating at 2,400 bits per second (b/s).

- Normally, each of the two channels supports transmissions in one direction only; in the event of a channel outage, the full-duplex capability of the remaining channel is used to support two-way transmissions.

This network has proven to be highly effective. However, because of the direct, dedicated, redundant connections, it is relatively expensive.

3.3 ALTERNATIVE 2, ENHANCED NADIN IA

The second alternative considered for NAS-NAS communications support is the use of NADIN, essentially as configured under the Level IA implementation. This network has also been described in Section 2. Of particular interest in this analysis are the following features (see Figure 3-2):

- A NADIN concentrator will be located at each of the 20 CONUS ARTCCs, collocated with the NAS 9020 computer complexes.

- Using this alternative, each NAS-NAS message would always be routed through one or both NADIN switches, located at the Atlanta and Salt Lake City ARTCCs.

- Using this alternative, NAS-NAS message traffic would have to contend with other high-priority ATC traffic for use of the network backbone links.

- Under the Level IA implementation, NADIN backbone links will consist of one or two full-duplex, voice-grade channels, each operating at 9,600 b/s; the multiplicity (and, hence, capacity) of these links can be increased to meet added requirements.

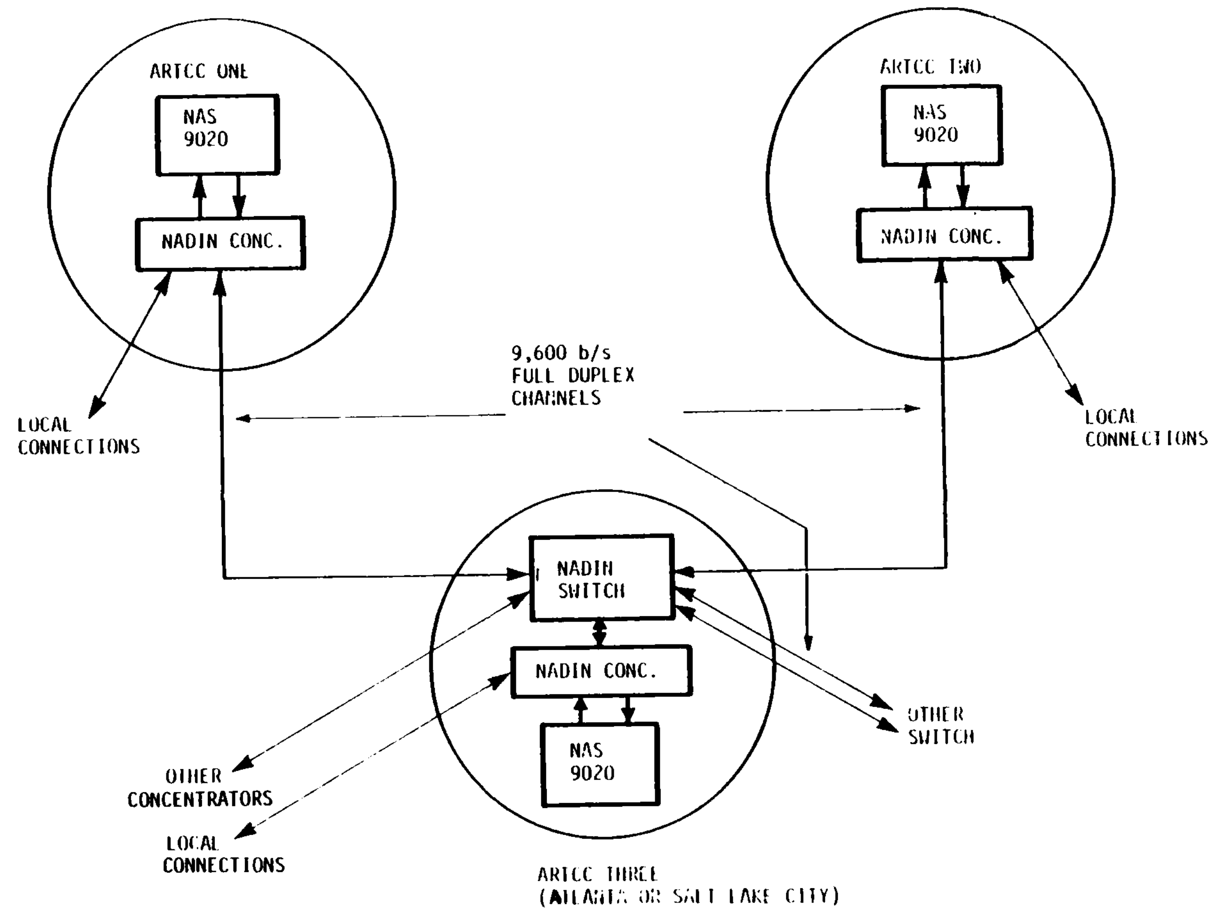


FIGURE 3-2: TYPICAL NAS-NAS MESSAGE PATHS, ALTERNATIVE 2

Alternative 2 would eliminate the need, and therefore the cost, for operating and maintaining the current NAS-NAS Network. Since NADIN IA has been designed for a variety of users and will include interfaces with the NAS 9020 computers, the cost to implement Alternative 2 should be relatively small. Specifically, the only major costs involved would be costs for minor modifications to the 9020 software (to adapt NAS-NAS messages to the NADIN interface) and costs for increasing link capacities to insure that the NAS-NAS delay constraint is met.

An analysis has been performed (see Appendix A) of the network delays that would result if the NAS-NAS traffic were directly added to NADIN IA. That analysis indicated that the capacities would have to be increased on fifteen of the NADIN IA backbone links in order that the NAS-NAS delay constraint be met. Table 3-1 identifies the specific links involved.

3.4 ALTERNATIVE 3, ENHANCED NADIN ARCHITECTURE

The third alternative involves a significant modification to NADIN. All NADIN concentrator nodes would be converted into combined concentrator/packet-switch nodes. Most of the message processing functions would remain with the two NADIN IA message switches.

The backbone nodes (packet switches) for this alternative would be interconnected so as to create a distributed network (see Figure 3-3). The specific links and link capacities would be selected so that:

- network delay constraints were not exceeded,
- each pair of switches would be (directly or indirectly) connected by at least two non-overlapping routes, and
- network costs would be minimized.

Under Alternative 3 it would still be necessary to route some messages (but not NAS-NAS messages) through the message switches at Atlanta and Salt Lake City. These would primarily include those messages that require recording for historical purposes, those associated with external systems and those that are generated with less sophisticated

LINK NODES		NUMBER OF 9,600 B/S CHANNELS ON LINK	
		NADIN IA	ENHANCED NADIN IA
Atlanta (C)	Atlanta (S)	1	2
Boston	Atlanta (S)	1	1
Chicago	Atlanta (S)	1	2
Cleveland	Atlanta (S)	1	2
Indianapolis	Atlanta (S)	1	2
Jacksonville	Atlanta (S)	1	2
Memphis	Atlanta (S)	1	2
Miami	Atlanta (S)	1	2
Minneapolis	Atlanta (S)	1	2
New York	Atlanta (S)	1	2
Washington	Atlanta (S)	1	2
Atlanta (S)	Salt Lake City (S)	2	2
Albuquerque	Salt Lake City (S)	1	1
Denver	Salt Lake City (S)	1	2
Fort Worth	Salt Lake City (S)	1	2
Houston	Salt Lake City (S)	1	2
Kansas City	Salt Lake City (S)	1	2
Los Angeles	Salt Lake City (S)	1	1
Oakland	Salt Lake City (S)	1	1
Salt Lake City (C)	Salt Lake City (S)	1	2
Seattle	Salt Lake City (S)	1	1
TOTAL		22	37

NOTES:

1. The Atlanta and Salt Lake City nodes are indicated as either being concentrators (C) or switches (S).

2. Backbone links to off-shore centers are not included.

TABLE 3-1: LINK CAPACITY MODIFICATIONS UNDER ALTERNATIVE 2

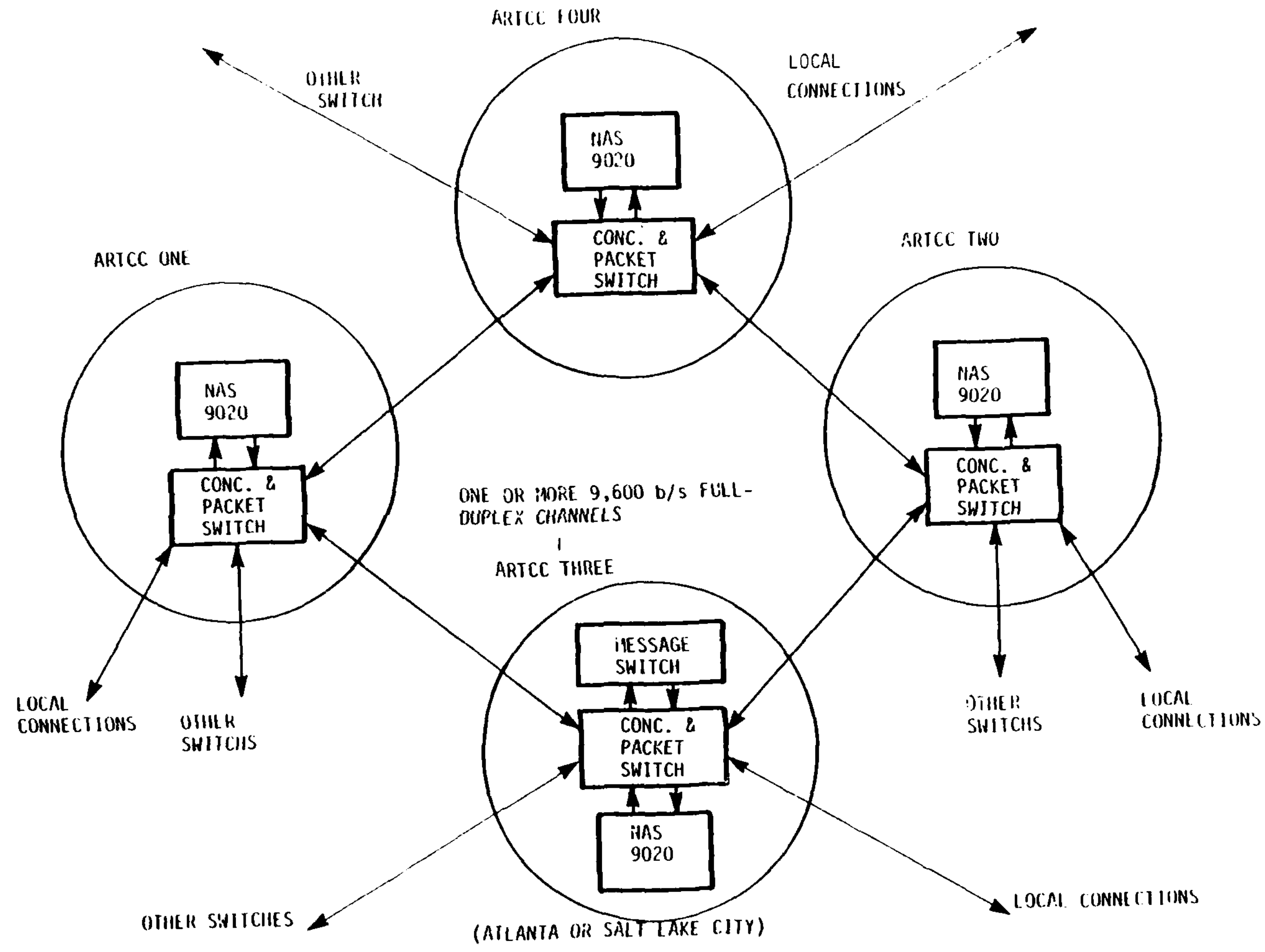


FIGURE 3-3: TYPICAL NAS-NAS MESSAGE PATHS, ALTERNATIVE 3

terminal equipment. There will never be a requirement to route a message through both switches.

A more complete discussion of this concept and its impact on the NADIN architecture are presented in Appendix B. An analysis was performed to determine a typical topology for such a network; i.e., linkages and link capacities. The analysis is presented in Appendix C; the optimal topology determined is indicated in Figure 3-4.

3.5 ALTERNATIVE 4, NAS-NAS/NADIN IA

The fourth alternative retains the basic NAS-NAS Network, but eliminates the redundant line on each link. This cuts the cost almost in half, but also reduces link reliability.

To provide back-up service in the event of a NAS-NAS line outage, this alternative includes an interface with NADIN IA. Since NADIN would serve the NAS-NAS traffic only sporadically, there need be no enhancement of NADIN IA specifically to accommodate such traffic. As a result, the primary NAS-NAS service under this alternative would be essentially the equivalent to that under the current NAS-NAS Network. The back-up service, although an improvement over the manual back-up system for the current network, would be expected to be used more often, and would not provide as good service as the current redundant lines.

3.6 ALTERNATIVE 5, REDUNDANT NADIN IA

A major difference between Alternative 2 and the other three alternatives defined above is the quality of the back-up service, should a primary line be lost. Alternative 1 includes redundant lines for such contingencies; Alternative 3 provides alternate routes; Alternative 4 uses NADIN IA. Should a primary line under Alternative 2 be lost, back-up service would be provided by a dial-up, circuit-switched system.

Alternative 5 attempts to overcome this limitation by including all the enhancements to NADIN IA as are included under Alternative 2 and by further including one additional 9600 b/s line on each backbone link. Thus the loss of any one line will result in no service degradation.

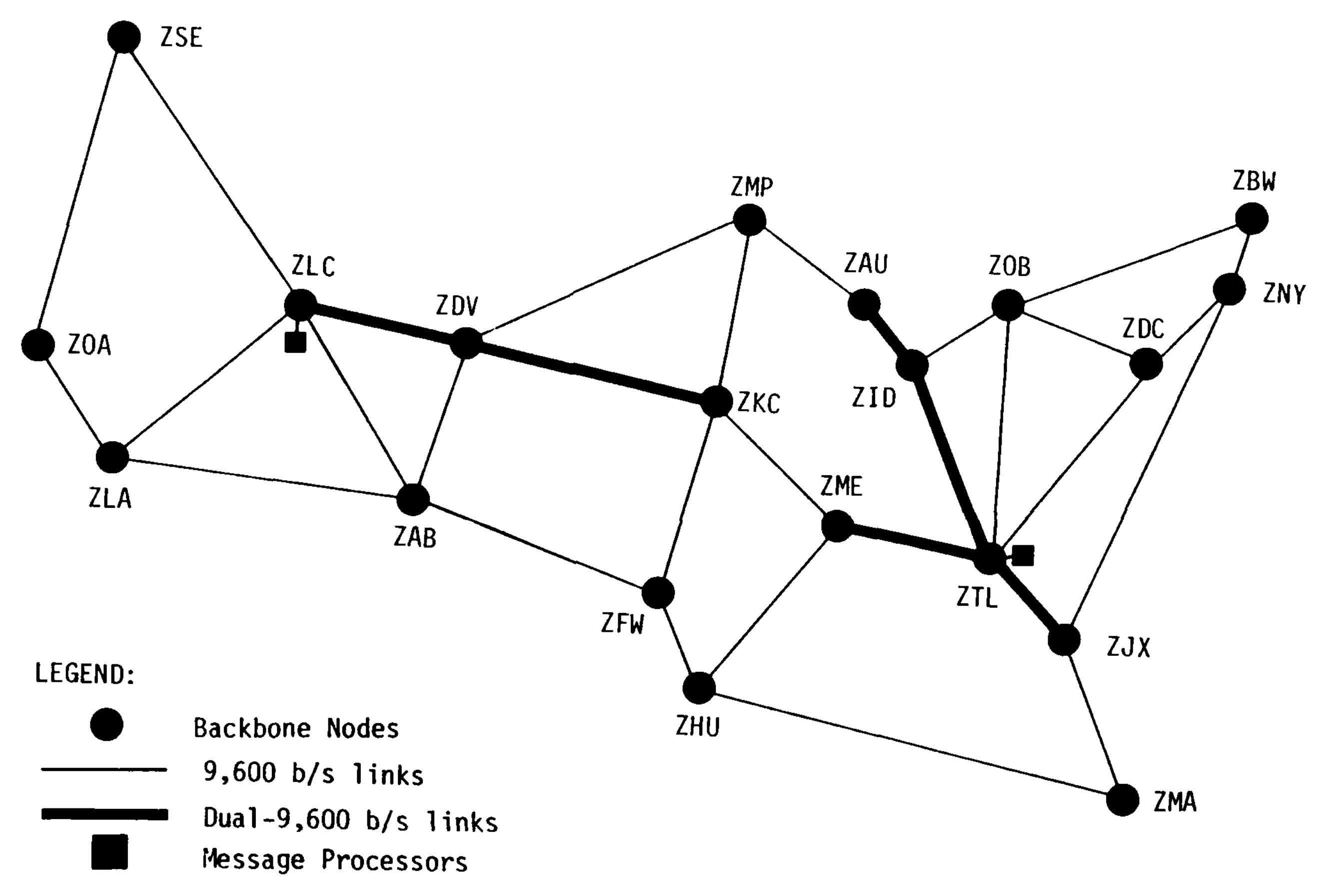


FIGURE 3-4: OPTIMAL ALTERNATIVE 3 CONFIGURATION

SECTION 4

ANALYSIS OF ALTERNATIVES

4.1 INTRODUCTION

As described in Section 3, the five alternatives considered for supporting NAS-NAS communications can meet all NAS-NAS requirements. Selection of a preferred alternative must thus be based on the comparison of additional features each provides and cost. Review of the five alternatives reveals four major areas to be considered in such a comparison. These are cost, throughput performance, back-up service and long-range potential. Only the first, cost, provides for a strictly quantitative comparison.

4.1.1 Cost

The methodology and parameters used to determine comparative costs for the five alternatives are presented in Appendix D. The major considerations include:

- A single comparative cost is determined for each alternative; this is the ten-year life cycle cost.
- The life cycle cost is calculated in terms of present value in 1983, assuming a ten percent net annual discount rate.
- The Multi-Schedule Private Line (MPL) tariffs are assumed to apply for the communications links under all five alternatives.
- It is assumed that funds required to implement NADIN IA without further enhancements and to operate it for ten years will be committed regardless of the NAS-NAS alternative selected. Thus, only incremental enhancements costs are included.

4.1.2 Throughput Performance

One facet of throughput performance, i.e., the end-to-end delays under projected 1988 throughput requirements, is actually reflected in the costs determined for each alternative. Thus, links are added and/or link capacities increased, as needed, to meet the delay constraints. The cost for such adjustments are included in the life cycle cost calculations.

This category of comparison thus reflects primarily the ability of the alternatives to handle temporary surges in throughput requirements. Generally, systems with more excess capacity or with means of avoiding further use of nearly congested links would rate better under this area of comparison.

4.1.3 Back-Up Service

Both the NAS-NAS Network and NADIN have been designed to provide high availability/reliability. There are, however, major differences in the quality of service available among the five alternatives should a primary line be lost. Further, some, through redundancy or alternate routing, include a back-up capability within the primary service. This category of comparison thus reflects the combination of the quality of back-up service and the likelihood that the back-up service would be required.

4.1.4 Long-Range Potential

Long-range potential is used here to refer to the benefits that might be realized from implementing a specific NAS-NAS alternative relative to broader, long-range ATC objectives and requirements. The ability to handle increasing traffic levels is actually reflected under throughput performance, and therefore is specifically excluded from this area of comparison.

The major considerations under long-range potential are thus the ability of each alternative to support or facilitate major long-range ATC programs. These primarily include:

- the ATC Computer Replacement Program (CRP),
- the Advanced EnRoute Automation Program (AERA), and

- Center Back-Up, which is associated with, but basically separate from, both CRP and AERA.

4.2 ALTERNATIVE 1, THE NAS-NAS NETWORK

Since the NAS-NAS Network exists and is operationally satisfactory, analysis of Alternative 1 has been directed primarily to the establishment of a basis for comparisons among the alternatives. Of specific interest are the expected delays under projected 1988 message traffic levels and the cost of retaining the NAS-NAS Network.

4.2.1 Alternative 1 Throughput Performance

Under Alternative 1 the transmission of a NAS-NAS message would involve use of only a single network link. Further, only NAS-NAS traffic and associated link control traffic would be transmitted on that link. As a result the greatest network delays would be encountered on the channel carrying the greatest volume of NAS-NAS traffic.

The data in Section 2 identifies the Miami-to-Jacksonville channel as the busiest in the NAS-NAS Network. It has been projected that in 1988 there would be 2,332 NAS-NAS messages transmitted over that channel during a peak hour, with each message averaging 37.7 (9-bit) characters. This projection includes all bits, characters and messages transmitted as overhead on the channel.

This message transmission requirement translates into a gross throughput requirement (GT) of:

$$GT = 2{,}332 \times 37.7 \times 9/3600$$
$$= 220 \text{ b/s during the peak hour.}$$

The average message transmission time (TF) on the 2400 b/s channel would be:

$$TF = 37.7 \times 9/2400 = .141 \text{ seconds}$$

The average queueing delay (TQ) prior to transmission of a message would be:

$$TQ = TF \times U/(1-U)$$

where U = the link utilization

$= GT/2400$

$= 220/2400 = .092$

Thus: $TQ = .141 \times .092/.908 = .014$ seconds

The queueing delay and transmission time are the only significant "network" delays encountered under Alternative 1. Thus the average network delay (TD) on the busiest channel would be:

$$TD = TF + TQ$$

$= .141 + .014 = .16$ seconds

This maximum average delay is well within the one second delay constraint identified for the NAS-NAS traffic. This, together with the very low link utilization (.092), represents a very high level of throughput performance.

The above calculations are based on standard communications analysis models. They are discussed in more general terms as part of the Alternative 2 analysis in Appendix A.

4.2.2 Alternative 1 Costs

Since the NAS-NAS Network exists and since the link capacities are sufficient for the projected 1988 traffic, the only costs associated with Alternative 1 are the monthly charges by the communications carrier. Under the MPL tariffs these include:

- a fixed monthly charge per channel ($51.72),
- an inter-exchange mileage charge (IXC) for each channel,

- a station terminal (drop) charge for each drop on a channel ($26.30), and

- a channel conditioning charge for each drop on a channel ($15.50).

The IXC for one channel on each of the 45 NAS-NAS links is shown in Table 4-1. Since each link has two channels and each channel requires two drops, the monthly recurring cost (RC) would be determined as shown below:

Fixed Charges	:	45 x 2 x $51.72	=	$ 4,655
IXC	:	2 x $18,746	=	37,492
Drop Charges	:	45 x 2 x 2 x $26.30	=	4,734
Conditioning Charges	:	45 x 2 x 2 x $15.50	=	2,790
		RC	=	$49,671

The *life-cycle cost used in comparing* the alternatives includes all one-time costs and the present value (PV) of all recurring costs, applicable over a 10 year system lifetime. Since there are no one-time costs for Alternative 1, the life-cycle cost (LC) would be (see Appendix D):

$$LC = PV = RC \times (1-(1+D)^{-m})/D$$

where D = the assumed net discount rate

= .008 per month (0.1 per year)

m = system lifetime

= 120 months

Thus: LC = $49,671 x 77.0 = $3.82 million

LINK NODES		DISTANCE (MILES)	IXC ($/CHANNEL/MONTH)
Albuquerque	Denver	361.6	$313.20
	Fort Worth	568.9	456.20
	Kansas City	704.0	549.50
	Los Angeles	671.1	526.70
Atlanta	Houston	693.4	542.10
	Indianapolis	454.2	377.00
	Jacksonville	232.3	223.90
	Memphis	351.1	305.90
	Washington	545.4	440.00
Boston	Cleveland	561.7	451.30
	New York	158.7	173.20
Chicago	Cleveland	317.5	282.70
	Indianapolis	177.9	186.40
	Kansas City	396.7	337.40
	Minneapolis	314.2	280.50
Cleveland	Indianapolis	232.3	223.90
	Minneapolis	598.6	476.70
	New York	476.3	392.30
	Washington	288.0	262.40
Denver	Kansas City	555.8	447.20
	Los Angeles	846.8	648.00
	Minneapolis	684.9	536.20
	Salt Lake City	359.4	311.70
Fort Worth	Houston	222.5	217.20
	Kansas City	437.2	365.40
	Memphis	435.8	364.40
Houston	Jacksonville	804.1	618.50
	Memphis	473.1	390.10
	Miami	972.2	734.50

TABLE 4-1: INTEREXCHANGE MILEAGE CHARGE (IXC) PER CHANNEL, ALTERNATIVE 1 (Page 1 of 2)

LINK NODES		DISTANCE (MILES)	IXC ($/CHANNEL/MONTH)
Indianapolis	Kansas City Memphis Washington	467.6 384.7 461.1	$ 386.30 329.10 381.80
Jacksonville	Miami New York Washington	356.3 857.3 633.3	309.50 655.20 500.60
Kansas City	Memphis Minneapolis	369.3 408.3	318.50 345.40
Los Angeles	Oakland Salt Lake City	323.0 589.7	286.50 470.60
Miami	New York	1,118.2	803.30
Minneapolis	Salt Lake City	988.3	745.60
New York	Washington	264.3	246.00
Salt Lake City	Oakland Seattle	586.1 684.4	468.10 535.90
Oakland	Seattle	675.2	529.50
TOTAL IXC (one channel per link)			$18,746.00

TABLE 4-1: INTEREXCHANGE MILEAGE CHARGE (IXC) PER CHANNEL, ALTERNATIVE 1 (Page 2 of 2)

4.2.3 Alternative 1 Back-Up Service

The high availability/reliability of the current NAS-NAS Network is provided through three design elements:

- point-to-point connections between each pair of centers that exchange NAS-NAS messages,
- redundant full-duplex lines and interfaces for each interconnection, and
- a manual back-up system, should both lines be lost.

The first two elements assure high availability for at least one end-to-end connection between two centers. The parallel redundant lines are, however, more susceptible to simultaneous outage from external causes (e.g. storms) than, for example, a network providing alternative routing. The last design element represents a relatively poor quality back-up service, on those rare occasions when it is needed.

4.2.4 Alternative 1 Long-Range Potential

The current NAS-NAS Network offers little long-range potential, as considered for this study. The multiple interfaces that this network requires at each center tend to make the computer replacement process (e.g., switch-over and testing) more difficult. Further, since this network provides communications from one center to only a limited number of other centers, it could not directly support Center Back-Up concepts.

4.3 ALTERNATIVE 2, ENHANCED NADIN IA

It has been assumed for this study that the Level IA implementation of NADIN will be completed in 1983. The incorporation of the NAS-NAS service into NADIN under Alternative 2 would thus primarily require:

- modifying NAS 9020 software to direct NAS-NAS messages to the appropriate output adaptor and to include information required by NADIN (e.g., message destination) in the NAS-NAS message, and

- making the necessary modifications to insure that the NAS-NAS message delay contraint is not exceeded.

4.3.1 Alternative 2 Throughput Performance

NADIN specifications (Reference 6) require that average peak-period network (end-to-end) delays for random message frames be no greater than two seconds. In order to meet that requirement for traffic to be handled under the Level IA implementation, it has been further specified (Reference 9) that:

- each link between a NADIN switch and a NADIN concentrator be a full-duplex, voice-grade channel, operating at 9,600 b/s, and

- the link between the two NADIN switches consist of two full-duplex, voice-grade channels, each operating at 9,600 b/s.

The delay constraint for NAS-NAS message traffic is more demanding; i.e., the average peak-period network delay must be no greater than one second. The impact of implementing Alternative 2, on the delays for both NAS-NAS traffic and NADIN IA traffic, has been analyzed. That analysis (see Appendix A) determined:

1. The overall throughput performance would still meet the NADIN requirements.

2. By 1988, sixty-three percent of the NAS-NAS origin/destination pairs would experience peak-period message delays averaging more than one second, if NADIN IA were left essentially unchanged.

3. The major contributing factor to the excessive delays are the queueing delays on the busier switch-to-concentrator legs of the message paths.

Several approaches are possible for reducing such delays. As suggested earlier, this study considered only the increasing of the number and/or capacity of the backbone links. The required modifications were shown in Table 3-1. Although these modifications assure that the NAS-NAS requirements are met, the throughput performance is relatively low, especially on those links retaining only a single 9,600 b/s line.

4.3.2 Alternative 2 Costs

Alternative 2 involves both one-time and recurring costs. The one-time cost items include installation charges and modem purchases associated with the added channels and the cost of modifying the 9020 software that controls the preparation and output of NAS-NAS messages. Installation costs associated with the added channels would apply only to 13 of the 15 added channels. This results from the fact that two of the added channels are between the switch and concentrator at Atlanta and at Salt Lake City. Those links are essentially internal to the respective ARTCCs and should require no significant commercial service. It is assumed, however, that modems would be purchased for those channels.

From Appendix D, the pertinent one-time charges would be:

- a station installation charge per drop per added commercial channel ($57),
- a channel conditioning equipment installation charge per drop per added commercial channel ($171),
- modem cost per drop per added channel ($8,500), and
- *software development costs* ($150 per instruction).

It is estimated that approximately 400 instructions would be required to modify the software. Thus the one-time costs (OC) would be determined as shown below:

Modems	:	15 x 2 x $8500	=	$ 255,000
Station Installation	:	13 x 2 x $57	=	1,482
Conditioning Installation	:	13 x 2 x $171	=	4,446
Software	:	400 x $150	=	60,000
		OC	=	$ 320,928

The recurring costs for Alternative 2 include primarily the monthly charges associated with the 13 additional commercial channels. Table 4-2 shows the IXC for these channels. (Note, only the column titled Alternative 2 applies here; the column titled NADIN IA is

LINK NODES*		DISTANCE (MILES)	IXC ($/MONTH)	
			NADIN IA	ALTERNATIVE 2
Altanta (C)	Atlanta (S)	0	$ 0	$ 0
Boston		951.2	720.00	0
Chicago		620.0	491.50	491.50
Cleveland		558.7	449.10	449.10
Indianapolis		454.2	377.00	377.00
Jacksonville		232.3	224.00	224.00
Memphis		351.1	305.90	305.90
Miami		581.4	464.90	464.90
Minneapolis		911.5	692.60	692.60
New York		802.1	617.10	617.10
Washington		545.4	440.00	440.00
Atlanta (S)	Salt Lake City (S)	1,599.5	2,010.90**	0
Albuquerque		485.8	398.90	0
Denver		359.4	311.70	311.70
Fort Worth		983.3	742.20	742.20
Houston		1,190.1	833.50	833.50
Kansas City		914.9	695.00	695.00
Los Angeles		589.7	470.60	0
Oakland		586.1	468.10	0
Salt Lake City (C)		0	0	0
Seattle		684.4	535.90	0
TOTAL IXC			$11,248.90	$6,644.50

* The Atlanta and Salt Lake City nodes are distinguished as being either concentrators (C) or switches (S).

** Value reflects two 9,600 b/s channels.

TABLE 4-2: INTEREXCHANGE MILEAGE CHARGE (IXC), ALTERNATIVE 2

included for later reference in considering Alternative 3.) The monthly recurring cost (RC) would be determined as shown below:

Fixed Charge	:	13 x \$51.72	=	\$	672
IXC	:		=		6,645
Drop Charge	:	13 x 2 x \$26.30	=		684
Conditioning Charge	:	13 x 2 x \$15.50	=		403
		RC	=	\$	8,404

The present value (PV) of the recurring charges would be:

PV = \$8,404 x 77.0 = \$647,108

The life-cycle cost (LC) would then be:

LC = OC + PV

= \$320,928 + \$647,108 = \$.97 million

4.3.3 Alternative 2 Back-Up Service

The high availability/reliability of NADIN IA is provided through two design elements:

- multiprocessor design of concentrators and switches, and
- a dial back-up system, including dial-up connections to the "other" switch should one switch be down.

Although the dial back-up system would be a major improvement over the NAS-NAS Network's manual back-up system, the likelihood that the back-up system would have to be used would be greater under Alternative 2. This results from the increased number of links (2 or 3) for each connection and the absence of redundant lines under Alternative 2.

4.3.4 Alternative 2 Long-Range Potential

Alternative 2 provides two features of importance to longer-range FAA objectives. First, there need be no dedicated NAS 9020 input/output ports for NAS-NAS communications. Rather, NAS-NAS traffic will use the same ports provided for general NADIN traffic. This would greatly facilitate switch-over and testing for the replacement computer. Second, under Alternative 2 a NAS-NAS message from one center can easily be routed to any other center, not just neighboring centers. This would greatly facilitate support for almost any Center Back-Up concept.

4.4 ALTERNATIVE 3, ENHANCED NADIN ARCHITECTURE

Alternative 3 requires that the NADIN architecture be modified so that:

- each of the existing CONUS nodes would contain a concentrator and a packet switch,

- the Atlanta and Salt Lake City nodes would also include message switches, operating essentially like the NADIN IA switches for certain classes of messages, and

- nodes would be interconnected in a manner that would provide at least two non-overlapping routes between each pair of nodes.

4.4.1 Alternative 3 Throughput Performance

Appendix C describes the analysis performed to determine a minimal cost configuration with the above characteristics that also satisfies the NADIN and NAS-NAS end-to-end delay constraints. Figure 3-4 depicted the configuration determined to be optimal. That configuration is made up of 31 links, involving thirty-seven 9,600 b/s channels. Nine of those channels are also included in the NADIN IA implementation.

Although the link capacities under Alternative 3 were selected so as to meet delay constraints, just as with Alternative 2, Alternative 3 would have significantly greater throughput performance. This is due to the availability of alternate routes between each pair of nodes, to help distribute the impact of temporary surges in demand.

4.4.2 Alternative 3 Costs

Unlike the other alternatives analyzed, Alternative 3 would involve major modifications to NADIN. This leads to a number of unique considerations related to system costs. The most significant of these are:

- the treatment of (unmodified) NADIN IA operating costs, which were ignored when considering the other alternatives, and
- NADIN hardware/software modification costs.

For the other alternatives it has been assumed that the Level IA implementation of NADIN would be retained and operated regardless of the alternative selected for handling NAS-NAS traffic. Thus, the recurring costs associated with the NADIN IA channels were not assigned as costs for those alternatives; only the costs associated with modifications (additions) were assigned to pertinent alternatives.

The modifications associated with Alternative 3 are not simple additions. Rather some items associated with NADIN IA are dropped and some new items are added. In order to insure comparability between the costs for this and the other alternatives, it has been necessary to determine the gross recurring cost for Alternative 3 and to reduce that total by the recurring costs of operating NADIN IA without any modifications.

No detailed analysis has been made of the specific hardware and software requirements for Alternative 3. Rather, in order to obtain a reasonable cost estimate, it has been assumed that an approach such as shown in Figure 4-1 would be used.

Under this concept the original NADIN concentrator hardware would be retained as the network interface for local connections (the NAS 9020 computer, FSSs, FDIO remote site equipment, etc.). The concentrator, rather than directing messages to the Atlanta or Salt Lake City switch, would direct all messages (other than those that are locally switched)

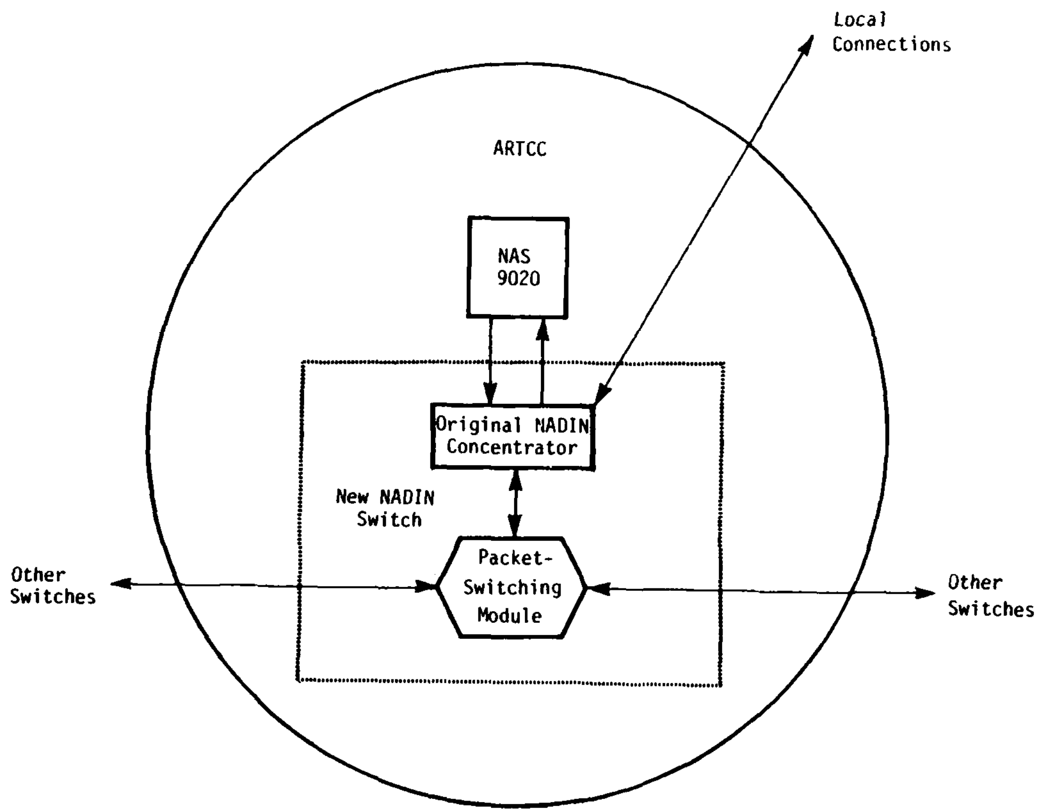


FIGURE 4-1: ALTERNATIVE 3 NADIN SWITCH CONCEPT

to a collocated switching module. Modules of this nature are available commercially, complete with networking software.

The one-time costs to implement this concept would thus include the cost to develop (or purchase and appropriately modify) the switching modules together with the software and the cost of modifying NADIN concentrator software. The former would cost approximately $75,000 per module; the latter, including major testing and debugging, is estimated to cost approximately $1.2 million.

Based on the above considerations, the one-time costs associated with Alternative 3 would include:

- switching module costs, including software,
- modem costs,
- installation costs for 28 new channels,
- NAS 9020 software modification costs (assumed to be equal to those for Alternative 2), and
- NADIN software modification costs.

The one-time cost (OC) for Alternative 3 would thus be determined as shown below:

Switching Module	:	20 x $75,000	=	$ 1,500,000
Modems	:	2 x 15 x $8,500	=	255,000
Station Installation	:	28 x 2 x $57	=	3,192
Conditioning Installation	:	28 x 2 x $171	=	9,576
9020 Software	:	400 x $150	=	60,000
NADIN Software	:		=	1,200,000
		OC	=	$ 3,027,768

As suggested earlier, the recurring cost has been determined by considering the monthly charges for the full, modified network and reducing these by the similar charges

that would be incurred if the unmodified NADIN IA were retained. For the reconfigured network the gross recurring cost (GRC) would be determined as shown below:

Fixed Charge	:	37 x $51.72	=	$ 1,914
IXC (see Table 4-3)	:		=	13,620
Drop Charge	:	37 x 2 x $26.30	=	1,946
Conditioning Charge	:	37 x 2 x $15.50	=	1,147
		GRC	=	$ 18,627

For the unmodified NADIN IA, the base recurring cost (BRC) would be determined as shown below:

Fixed Charge	:	22 x $51.72	=	$ 1,138
IXC (see Table 4-2)	:		=	11,249
Drop Charge	:	22 x 2 x $26.30	=	1,157
Conditioning Charge	:	22 x 2 x $15.50	=	682
		BRC	=	$ 14,226

The net recurring cost (RC) would then be:

RC = GRC - BRC
= $18,627 - $14,226 = $4,401

The present value (PV) of the recurring charges would be :

PV = $4,401 x 77.0 = $338,877

The life-cycle cost (LC) would be

LC = $3,027,768 + $338,877 = $3.37 million

LINK NODES		DISTANCE (MILES)	CHANNELS	IXC ($/MONTH)
Seattle	Oakland	675.2	1	$ 529.50
Seattle	Salt Lake City	684.4	1	535.90
Oakland	Los Angeles	323.0	1	286.50
Los Angeles	Salt Lake City	589.7	1	475.60
Los Angeles	Albuquerque	671.1	1	526.70
Salt Lake City	Albuquerque	485.8	1	398.90
Salt Lake City	Denver	359.4	2	623.30
Denver	Albuquerque	361.6	1	313.20
Denver	Minneapolis	684.9	1	536.20
Denver	Kansas City	555.8	2	894.30
Albuquerque	Fort Worth	568.9	1	456.20
Kansas City	Minneapolis	408.3	1	345.40
Kansas City	Fort Worth	437.2	1	365.40
Minneapolis	Chicago	314.2	1	280.50
Chicago	Indianapolis	177.9	2	372.80
Kansas City	Memphis	369.3	1	318.50
Fort Worth	Houston	222.5	1	217.20
Houston	Memphis	473.1	1	390.10
Indianapolis	Cleveland	232.3	1	223.90
Indianapolis	Atlanta	454.2	2	754.10
Memphis	Atlanta	702.2	2	611.80
Houston	Miami	972.2	1	734.50
Atlanta	Cleveland	558.7	1	449.20
Atlanta	Washington	545.4	1	440.00
Atlanta	Jacksonville	232.3	2	447.90
Cleveland	Boston	561.7	1	451.30
Cleveland	Washington	288.0	1	262.40
Washington	New York	264.3	1	246.00
New York	Boston	158.7	1	173.20
Jacksonville	New York	857.3	1	655.20
Jacksonville	Miami	356.3	1	309.50
TOTALS			37	$13,620.00

TABLE 4-3: INTEREXCHANGE MILEAGE CHARGE (IXC), ALTERNATIVE 3

4.4.3 Alternative 3 Back-Up Service

Alternative 3 requires no separate back-up service. Should one link be lost, the packet routing/switching function will find an alternate route and insure that no links are overloaded. The network delays under such circumstances might be slightly greater than when all links are functioning, but generally there should be no significant degradation in service quality.

The fact that this alternative generally requires the use of two or more links for a connection does increase the likelihood that a specific primary route is lost, as compared with the single link, redundant NAS-NAS Network. Nevertheless, the availability of alternate routes and the geographical distribution of the links make it less likely that a connection would be totally lost. The NAS-NAS Network, on the other hand, is more susceptible to complete loss of a (redundant) connection as the result of storms or other external causes.

4.4.4 Alternative 3 Long-Range Potential

Alternative 3 offers the same longer-range benefits as Alternative 2; i. e., reduced computer interfaces and interconnection between all centers. Alternative 3 can, however, provide generally better support to the Center Back-Up concepts in that:

- it is less dependent on routes through the two centralized message-switch nodes,
- it provides more direct connections between neighboring centers, and
- it is less susceptible to link congestion.

4.5 ALTERNATIVE 4, NAS-NAS/NADIN IA

Alternative 4 combines the small network delays of the current NAS-NAS Network with the reduced cost of using NADIN. Specifically, this alternative retains one channel on each of the 45 NAS-NAS links and uses NADIN (as configured under the Level IA implementation) as a back-up in the event of NAS-NAS Network link outage. An operational variation on this alternative would involve the use of NADIN as the primary communications service and the use of NAS-NAS links only during periods when NADIN delays are too great or when there is a NADIN link outage.

4.5.1 Alternative 4 Throughput Performance

The throughput performance under Alternative 4 would be essentially the same as that under Alternative 1.

4.5.2 Alternative 4 Costs

It is assumed that under Alternative 4 there would be no significant modifications to NADIN IA. NAS 9020 software would, however, have to be modified, essentially as with Alternative 2. Thus the one-time cost (OC) for this alternative would be determined as shown below:

Software	:	400 x $150 =	$60,000
		OC =	$60,000

The recurring costs for Alternative 4 would be similar to those for Alternative 1, however each link would now include only a single channel. Thus the recurring cost (RC) would be determined as shown below:

Fixed Charge	:	45 x $51.72	=	$ 2,327
IXC (see Table 4-1)	:		=	18,746
Drop Charge	:	45 x 2 x $26.30	=	2,367
Conditioning Charge	:	45 x 2 x $15.50	=	1,395
		RC	=	$ 24,835

The present value (PV) of the recurring costs would thus be:

PV = $24,835 x 77.0 = $1,912,295

The life-cycle (LC) cost would be :

LC = $60,000 + $1,912,295 = $1.97 million

4.5.3 Alternative 4 Back-Up Service

The back-up service under Alternative 4 is NADIN IA. Although this is better than the Alternative 1 manual back-up service, it is more likely to be used because of the absence of link redundancy. The quality of this back-up service is generally good; however, it is subject to congestion, if required during a peak period.

4.5.4 Alternative 4 Long-Range Potential

Alternative 4 offers some improvement in terms of long-range potential relative to that under Alternative 1. It involves only half as many interfaces with the NAS 9020 computers, and it provides, through NADIN IA, interconnections between all centers. The fact that some NAS-NAS interfaces would still exist and that NADIN link capacities would not be increased, limit the long-range value of the improvements.

4.6 ALTERNATIVE 5, REDUNDANT NADIN IA

Alternative 5 is essentially the same as Alternative 2, except that one back-up channel would be added to each of the 21 NADIN links. This would improve service when primary channels experience outages. Except for this improved back-up service, there would be no significant change in performance.

4.6.1 Alternative 5 Throughput Performance

Under the basic concept of this alternative, the throughput performance would be identical with that of Alternative 2. It should be possible, however, with minimal additional software modifications to permit use of the redundant line at any time, thus further reducing queueing delays, especially during temporary surges in traffic.

4.6.2 Alternative 5 Costs

The only differences in cost between Alternatives 2 and 5 would be the added costs of installation (including modem purchase) and operation for the 21 back-up channels under Alternative 5. The added one-time costs (AOC) would be determined as below:

Modems	:	21 x 2 x $8,500	=	$	357,000
Station Installation	:	21 x 2 x $57	=		2,394
Conditioning Installation	:	21 x 2 x $171	=		7,182
		AOC	=	$	366,576

The added channels for this alternative basically duplicate the unmodified NADIN IA channels, except for the switch-to-switch link. Thus the added IXC for Alternative 5 would be equal to that shown for NADIN IA in Table 4-2 minus half the IXC for the switch-to-switch link (i.e., $2,010.90 ÷ 2 = $1,005). The added recurring cost (ARC) for Alternative 5 would be determined as shown below:

Fixed Charge	:	21 x $51.72	=	$	1,086
IXC	:	$11,249 - $1,005	=		10,244
Drop Charge	:	21 x 2 x $26.30	=		1,105
Conditioning Charge	:	21 x 2 x $15.50	=		651
		ARC	=	$	13,086

The added present value (APV) of the recurring costs would be:

APV = $13,086 x 77.0 = $1,007,622

The added life-cycle cost (ALC) would be:

ALC = AOC + APV
= $366,576 + $1,007,622 = $1.37 million

The total life-cycle cost (LC) would be obtained by adding the above result to the life-cycle cost for Alternative 2 ($.97 million), i.e.:

LC = $.97 million + $1.37 million = $2.34 million

4.6.3 Alternative 5 Back-Up Service

This alternative, like Alternative 1, uses redundant lines to minimize the likelihood of having to use the back-up service. Thus these two alternatives can be rated equivalently in this respect.

4.6.4 Alternative 5 Long-Range Potential

The long-range potential of this alternative is the same as that for Alternative 2.

SECTION 5

COMPARATIVE EVALUATION

5.1 INTRODUCTION

On the basis of cost alone, the preceding analysis indicates that the most efficient approach to supporting NAS-NAS communications would involve the use of NADIN IA, enhanced to provide greater link capacities (Alternative 2). The more subjective portions of that analysis indicate, however, that the higher costs for the other alternatives are generally associated with additional benefits. This appears particularly true for the Enhanced NADIN Architecture (Alternative 3).

5.2 COST AND BENEFIT COMPARISONS

The five alternatives considered for supporting NAS-NAS communications have been analyzed relative to four major areas of differences. These are:

- cost, in terms of the ten-year life cycle cost;
- throughput performance, reflecting primarily the ability to effectively handle temporary surges in demand;
- back-up service, reflecting the quality of the back-up service provided and the likelihood that it would be needed; and
- long-range potential, reflecting primarily the ability to facilitate and/or support the objectives of the ATC Computer Replacement Program and Center Back-Up concepts.

Relative to all four considerations, no one of the five alternatives stands out as the ideal selection. Each has its advantages and disadvantages. These are summarized in Table 5-1.

ALTERNATIVE	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
1. Current NAS-NAS Network	● High throughput performance. ● Good back-up service.	● Greatest cost. ● Least long-range potential.
2. Enhanced NADIN IA	● Least cost.	● Poorest back-up service. ● Just adequate throughput performance.
3. Enhanced NADIN Architecture	● Best back-up service. ● Best long-range potential. ● High throughput performance.	● High cost.
4. NAS-NAS/NADIN IA	● High throughput performance.	● Poor long-range potential.
5. Redundant NADIN IA	● Is not "poorest" in any category.	● Is not "best" in any category.

TABLE 5-1: MAJOR ADVANTAGES AND DISADVANTAGES OF NAS-NAS SERVICE ALTERNATIVES

In order to provide a more objective basis for comparison, judgemental values have been assigned for the three subjective areas, using 10 to represent "the best". The assigned ratings for each alternative are shown in Table 5-2 along with the associated cost.

5.3 INTERPRETATION OF RESULTS

Review of the results as presented in Table 5-2 reveal the following:

1. The major weakness of the current NAS-NAS network (Alternative 1), relative to the use of NADIN, is its low long-range potential. It is also the most expensive of the alternatives considered.

2. For approximately the same cost as the current network, the Enhanced NADIN Architecture (Alternative 3) can provide essentially equivalent service quality plus a major increase in long-range potential.

3. The three other alternatives involving the use of NADIN (Altrenatives 2, 4 and 5) can all support the basic NAS-NAS requirements at significantly reduced costs. Each of these, however, would involve giving up other nice-to-have features when compared with Alternative 3. Only the redundant NADIN IA (Alternative 5), the most expensive of the three, can be considered to provide service (throughput performance and back-up service) close to that of the current network, plus a long-range potential close to that of Alternative 3.

Item 2 above suggests that use of NADIN would be preferred over continued use of the current NAS-NAS Network. Item 3 above suggests that the best NADIN alternative depends on the cost-benefit trade offs. Such trade offs must be determined on a subjective basis, and can best be determined by FAA personnel more familiar with FAA priorities.

There are, however, certain considerations that suggest Alternative 3 as the most cost-beneficial approach. These include:

- The cost of the current NAS-NAS Network is not felt to be unreasonably high for the service quality provided. Thus cost is probably one of the least important of the factors considered.

ALTERNATIVE	COST (millions)	SUBJECTIVE RATINGS*		
		THROUGHPUT PERFORMANCE	BACK-UP SERVICE	LONG-RANGE POTENTIAL
1. Current NAS-NAS Network	$3.82	10	8	2
2. Enhanced NADIN IA	.97	6	5	6
3. Enhanced NADIN Architecture	3.37	9	10	10
4. NAS-NAS/ NADIN IA	1.97	10	6	4
5. Redundant NADIN IA	2.34	8	8	6

*Higher rating values = more desirable qualities.

TABLE 5-2: COSTS AND SUBJECTIVE RATINGS FOR NAS-NAS SERVICE ALTERNATIVES

- Alternative 3, more than any of the other NADIN alternatives considered, would provide the capability to support other more demanding FAA programs and communications requirements. Thus a smaller portion of the cost for Alternative 3 could be considered as being associated strictly with NAS-NAS service. This concept of sharing the cost can best be evaluated through an integrated study (such as is planned under Task 13).

5.4 OTHER CONSIDERATIONS

The evaluations above primarily suggest a general preference for NADIN over the current NAS-NAS Network. The identification of Alternative 3 as the most attractive of the four NADIN alternatives was based primarily on the long-range potential, especially the potential for supporting the ATC Computer Replacement Program and subsequent modifications of the computer system. Since the current NAS-NAS Network is expected to provide highly satisfactory service prior to computer replacement, there is no pressing requirement to replace that service. Rather, it would appear to be primarily important that any change in the service occur prior to computer replacement.

Further, since the advantages of Alternative 3 relate to its ability to support computer replacement and other FAA programs, it would be desirable that Alternative 3 be further tailored to insure more optimal support for those programs. Information pertinent to this is expected to be developed through three other tasks under this contract (Tasks 12, 13 and 14). It would thus appear prudent to delay any major activity to replace the current NAS-NAS Network until at least preliminary results are available from those studies.

In anticipation of implementing Alternative 3, or a variation of that concept, there are some areas of more detailed study that should be addressed. These include:

- an analysis of the feasibility and cost for converting the NADIN concentrators into combined concentrator/packet-switch units;

- a survey of other available hardware and software to support packet-switching networks of the type considered;

- an analysis of the impact on NADIN traffic in general that would result from the provision of special handling for selected message classes (including use of permanent virtual circuits for specific message classes); and

- a detailed consideration of the transition process from NADIN IA to the packet-switching enhancement.

APPENDIX A

ANALYSIS FOR ALTERNATIVE 2

APPENDIX A

ANALYSIS FOR ALTERNATIVE 2

A.1 PURPOSE AND SCOPE

This appendix investigates network delay times for NAS-NAS messages, should Alternative 2 be adopted, and determines modifications necessary to insure that delay constraints are met. It includes the assumptions, methodology and data used. This analysis has drawn heavily on the methodology and data presented in the Technical Data Package for NADIN Level IA (Reference 9, referred to hereafter as the Level IA Study).

A.2 GENERAL APPROACH

Under Alternative 2, NADIN, essentially as configured for NADIN IA, would be used as the communications utility for NAS-NAS message traffic. Thus the traffic between two centers would be routed from the NADIN concentrator collocated with the sending NAS 9020 computer, to the associated NADIN switch, and then to the NADIN concentrator collocated with the receiving NAS 9020 (possibly through the other NADIN switch).

For this analysis the 1983 peak-period NADIN message traffic identified in the Level IA Study has been assigned to specific NADIN backbone links. The projected 1983 NAS-NAS traffic has similarly been assigned to pertinent links. The effect of these cumulative throughput requirements on NAS-NAS message delays has been determined, using standard queueing models. Finally, the throughput growth by 1988 has been estimated and its effect on delays also determined.

In carrying out this analysis, the following assumptions have been used:

1. NADIN will be implemented with the double-star backbone configuration, illustrated in Figure A-1, by early 1983.

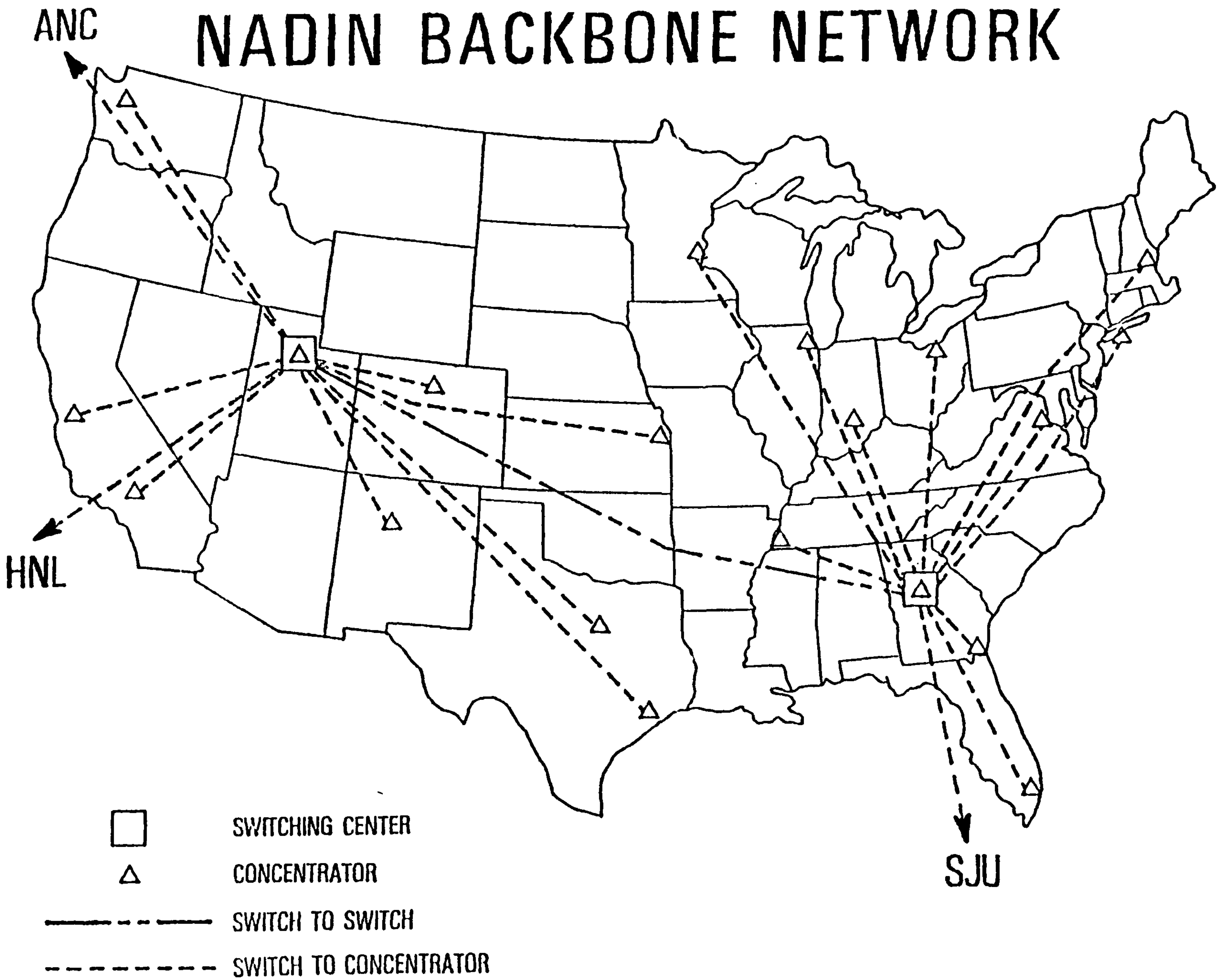


FIGURE A-1: NADIN BACKBONE NETWORK

2. Under the Level IA implementation, each NADIN switch-to-concentrator trunk will be a full-duplex, voice-grade channel operating at 9,600 bits per second (b/s). The switch-to-switch trunk will consist of two such channels.

3. A switch discipline will be implemented that will prevent the transfer of large files from unduly delaying the transmission of other messages (as suggested in the Level IA Study and Reference 14). In addition, efforts will be made to restrict the number of file transfers that occur during the same hour, through optimal scheduling of transfers that are required less frequently than once an hour.

4. In addition to the NAS-NAS traffic, NADIN backbone links will be used to transmit the following types of message traffic:

   - NADIN I - The traffic specified for initial NADIN implementation (see Appendix Z, Reference 6), including primarily that traffic currently handled by the Area B/Supplemental B, Airline and Military Utility B, Center B, AFTN and NASNET networks;

   - AFC - Messages disseminated from the Interim Flow Control Processor (IFCP) in Jacksonville (to ARTCCs, terminal areas, FSSs, ARINC and airlines) under the Interim Automated Flow Control program and flight data messages forwarded from the ARTCCs to the Central Flow Control Computer Complex (CFCCC) in Jacksonville (see Reference 15);

   - FSAS - All message and file transfers identified for the Flight Service Automation System (see Reference 14);

   - NFDC/IS - NOTAMs and interactive messages transferred between the National Flight Data Center (NFDC) in Washington and the Consolidated NOTAM System (CNS)/Airmen Information System (AIS) in Atlanta; plus NOTAMs transferred between the CNS and a back-up NOTAM processor in Salt Lake City (see Alternative 2 in Reference 16).

5. NADIN will also be used for other message traffic. However, such traffic will not use the backbone links; e.g.:

   - FDIO (FDEP) messages will be locally switched by each NADIN concentrator (as suggested in the Level IA Study and Reference 7), and;

   - All traffic between CNS and AWP/WMSC will involve only the NADIN Atlanta switch; collection and distribution of NOTAMs from or to other locations is included in the FSAS and Service A message traffic (the latter is not considered to be integrated into NADIN).

6. NADIN backbone traffic to and from the three off-shore centers (Anchorage, Honolulu and San Juan) will have negligible impact on NADIN's performance relative to NAS-NAS message traffic.

7. Between the Level IA implementation (1983) and 1988, NADIN message traffic will increase in proportion to the projected increase in IFR aircraft traffic; this has been conservatively estimated to be 22 percent.

A.3 THROUGHPUT REQUIREMENTS

Peak-period throughput requirements, measured in bits per second (b/s), have been determined for each NADIN backbone link. These represent the accumulated requirements of the four traffic categories identified above, plus the NAS-NAS requirements. The requirements have been calculated in two forms:

- Net throughput (NT) - the bits representing original messages that are to be transmitted per second, and

- Gross throughput (GT) - the total number of bits, including all overhead transmissions, that are to be transmitted per second.

Both requirements are calculated from the average message length (L, measured in characters per message) and the peak-period message frequency (F, measured in messages

per hour). Net throughput is the product of these two message characteristics, with appropriate conversion of units, i.e.:

$$NT = F \times L \times B/S$$

where $B = 8 =$ the number of bits per character,

$S = 3600 =$ the number of seconds per hour.

Thus:

$$NT = .002222 \times F \times L$$

Gross throughput reflects the addition of all other bit, character and message transmissions required by the network (NADIN) or link (ADCCP) protocols. These have been detailed in the Level IA Study and are summarized below:

- NADIN requires a header and trailer on each "message". Together these involve approximately 63 characters. A NADIN message is limited to 3700 characters. Thus, any actual message or file which contains more than 3700 characters must be broken down into two or more NADIN messages, with a header and trailer added to each.

- Messages are transmitted across the individual NADIN backbone links in frames with 245 or less characters. ADCCP adds frame control data, equivalent to 11 characters for each frame, and inserts additional zero bits to avoid ambiguity between data and synchronization bit strings. It has been determined that the zero insertion process increases the number of bits (and hence the number of equivalent characters) by about 1.6 percent.

- Both the network and link protocols transmit control messages on the lines. It has been estimated that each adds the equivalent of 3 percent to the transmissions.

- Finally, the control procedures cause the automatic retransmission of frames containing transmission errors. It has been conservatively estimated that 2.5 percent of all frames must be retransmitted.

Taking these overhead items into consideration, the gross message length (GL) and gross message frequency (GF) are determined from:

$$GL = [L + (a \times 63) + (b \times 11)] \times 1.016$$

where a = the smallest integer $\geq L/3700$,
b = the smallest integer $\geq [L + (a \times 63)]/245$.

$$GF = F \times 1.03 \times 1.03 \times 1.025$$

$$= 1.087 \times F.$$

The gross throughput is calculated as:

$$GT = GF \times GL \times B/S$$

$$= .00245\ F \times [L + (a \times 63) + (b \times 11)]$$

The message characteristics and associated 1983 throughput requirements for the five traffic categories considered are presented in the following subsections.

A.3.1 NADIN I Traffic

The Level IA Study used the design parameters from the NADIN Specifications (Appendix Z, Reference 6) as the basis for NADIN I throughput requirements. That study modified only the Area B message frequencies, to reflect more recent data. Those same, modified traffic characteristics have been used in this analysis. Not included in those data, are the requirements for the collection of flight data from ARTCCs for flow control purposes. This function is now considered part of the NADIN I requirements. For convenience in this study, those requirements are considered under AFC Traffic.

The nature of the NADIN I design data makes it impractical to differentiate the requirements for individual backbone links. Rather, the requirements have been distinguished only in terms of three types of transmissions:

- concentrator-to-switch,
- switch-to-concentrator, and
- switch-to-switch.

Table A-1 shows the message characteristics and the associated peak-period throughput for each of these types of transmission.

A.3.2 AFC Traffic

The study of Automated Flow Control (AFC) communications requirements (Reference 15) was being carried out simultaneously with the Level IA Study. As a consequence the Level IA Study reflected preliminary data and findings relative to the AFC message traffic. The data used below differ from that in the Level IA Study in three respects:

- treatment of the increase in number of pacing airports,
- consideration of flight data collection messages (as part of NADIN I) in addition to the dissemination of flow control messages (as part of NADIN IA), and
- minor revisions to the flow control message frequencies.

A.3.2.1 Pacing Airports

Flow control message traffic is concerned primarily with air traffic at selected busier airports, called pacing airports. Currently there are 17 pacing airports. This number is expected to increase to 35, sometime between 1983 and 1988. This increase is conservatively assumed to cause a doubling in AFC message traffic, in addition to increases caused by air traffic growth.

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
FROM	TO	MSG./HR.	MEAN CHAR.	NET	GROSS
Any NADIN Concentrator	Associated Switch	769	120	205.0	365.3
Either Switch	Any Associated Concentrator	810 14	120 3,000	216.0 93.4 309.4	384.7 110.0 494.7
Either Switch	Other Switch	2679	120	714.4	1272.5

Source: ARD-220-IA, Technical Data Package for NADIN Level IA, December, 1980

TABLE A-1: NADIN I PEAK PERIOD MESSAGE TRAFFIC

For this analysis it is convenient to reflect the impact of the additional pacing airports in the 1983 data. Growth in NADIN throughput requirements for subsequent years can then be considered uniform across the various message traffic categories.

A.3.2.2 <u>Flight Data Collection Messages</u>

Flight data messages are currently directed from the NAS 9020 computers at the 20 CONUS ARTCCs to the CFCCC in Jacksonville over a hybrid store-and-forward network. That network utilizes selected links of the NAS-NAS Network to transmit the messages to the NAS 9020 computers at five ARTCCs (called forwarding centers). These five computers are linked directly to the CFCCC. Under the NADIN I implementation the CFCCC will be directly connected to the Atlanta switch. Flight data messages will then be transmitted from each NAS 9020 computer to the collocated NADIN concentrator and then to the CFCCC over the NADIN backbone links.

Flight data message characteristics are shown in Table A-2. That table includes two groups of messages:

- Present Messages, i.e., those currently transmitted over the store-and-forward network, and

- Future Messages, i.e., those additional messages to be included in the flight data collection process in future years.

As with the increase in number of pacing airports, this analysis includes the "future" messages as part of the 1983 throughput requirements.

The baseline (1980) message frequencies have been obtained from Reference 15. The projected 1983 peak period frequencies have been determined by first doubling the baseline frequencies to reflect the increased number of pacing airports, and then considering a 3 percent annual growth; i.e.:

$$\text{Adjustment Factor} = 2 \times (1.03)^3 = 2.185$$

MESSAGE TYPE	BASELINE PEAK MSG./HR.	ADJUSTMENT FACTOR	1983 PEAK MSG./HR.	MEAN CHARACTERS
Present Messages:				
Flight Plans	191	2.185	417	57
Departure	1,002	2.185	2,189	57
Cancellation	100	2.185	219	42
Future Messages:				
Enroute	4,008	2.185	8,757	80
Amendments	1,002	2.185	2,189	80
Terminate Beacon	1,002	2.185	2,189	20
Average Message			15,960	67.5

Source: NAC WM.303G.02 AFC Requirements Analysis, December 30, 1980

TABLE A-2: CUMULATIVE AFC FLIGHT DATA MESSAGE CHARACTERISTICS

The data in Table A-2 reflects the cumulative messages arriving at the CFCCC. The fraction of messages that originate at each ARTCC is shown in Table A-3 (based on data in Reference 15) along with the associated message frequency.

The association of this traffic with specific NADIN backbone links is relatively direct. Traffic originating at a specific concentrator will exist on the link from that concentrator to the associated switch (indicated in Table A-3). The sum of all such traffic directed to the Salt Lake City switch will also exist on the Salt Lake City to Atlanta link. This traffic distribution and the associated throughput requirements are shown in Table A-4. In this and subsequent tables, the NADIN links are identified by the interconnected nodes, using the symbols defined in Table A-3.

A.3.2.3 Flow Control Dissemination Messages

The flow control message traffic expected to be carried by NADIN is characterized in terms of three message types, all originating or terminating at the IFCP in Jacksonville. These are identified in Table A-5. Message frequencies shown in that table reflect the 1980 baseline values (from Reference 15) and the projected 1983 values, obtained by use of the 2.185 adjustment factor discussed earlier. They apply directly only to messages leaving or arriving at the IFCP.

The distribution of this message traffic among the NADIN links has been estimated using the following procedures and assumptions:

1. The IFCP will interface NADIN at the Jacksonville concentrator. Thus the Jacksonville-to-Atlanta link will carry all the Type 1 and Type 2 traffic indicated in Table A-5, plus that portion (5 percent) of the Type 3 messages that originates at the Jacksonville ARTCC.

2. It has been estimated that each Type 1 and Type 2 message leaving the IFCP, destined for ARTCCs and ATCTs, will be addressed to an average of five destinations. The necessary duplication will be effected at the Atlanta switch. Thus there will be five times as many Type 1 and Type 2 messages for such destinations leaving the Atlanta switch as leaving the Jacksonville concentrator.

ARTCC/CONCENTRATOR			FRACTION OF FLIGHT DATA MESSAGE ORIGINS**	1983 PEAK MSG./HR.
SYMBOL	LOCATION	SWITCH*		
ZAB	Albuquerque	XLC	.048	766
ZTL	Atlanta	XTL	.055	878
ZBW	Boston	XTL	.035	559
ZAU	Chicago	XTL	.053	846
ZOB	Cleveland	XTL	.079	1,261
ZDV	Denver	XLC	.046	734
ZFW	Fort Worth	XLC	.049	782
ZHU	Houston	XLC	.036	575
ZID	Indianapolis	XTL	.078	1,245
ZJX	Jacksonville	XTL	.081	1,293
ZKC	Kansas City	XLC	.057	910
ZLA	Los Angeles	XLC	.030	479
ZME	Memphis	XTL	.067	1,069
ZMA	Miami	XTL	.047	750
ZMP	Minneapolis	XTL	.046	734
ZNY	New York	XTL	.055	878
ZOA	Oakland	XLC	.029	463
ZLC	Salt Lake City	XLC	.016	255
ZSE	Seattle	XLC	.031	495
ZDC	Washington	XTL	.061	974

* Symbol indicates associated NADIN switches, as follows:

XLC = Salt Lake City switch
XTL = Atlanta switch

** Source: NAC WM.303G.02 AFC Requirements Analysis, December 30, 1980.

TABLE A-3: DISTRIBUTION OF AFC FLIGHT DATA MESSAGE ORIGINS

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
FROM	TO	MSG./HR.	MEAN CHAR.	NET	GROSS
ZAB	XLC	766	67.5	114.9	265.6
ZTL	XTL	878	67.5	131.7	304.4
ZBW	XTL	559	67.5	83.9	193.8
ZAU	XTL	846	67.5	126.9	293.3
ZOB	XTL	1,261	67.5	189.2	437.2
ZDV	XLC	734	67.5	110.1	254.5
ZFW	XLC	782	67.5	117.3	271.1
ZHU	XLC	575	67.5	86.3	199.3
ZID	XTL	1,245	67.5	186.8	431.6
ZJX	XTL	1,293	67.5	194.0	448.3
ZKC	XLC	910	67.5	136.5	315.5
ZLA	XLC	479	67.5	71.9	166.1
ZME	XTL	1,069	67.5	160.4	370.6
ZMA	XTL	750	67.5	112.5	260.0
ZMP	XTL	734	67.5	110.1	254.5
ZNY	XTL	878	67.5	131.7	304.4
ZOA	XLC	463	67.5	69.5	160.5
ZLC	XLC	255	67.5	38.3	88.4
ZSE	XLC	495	67.5	74.3	171.6
ZDC	XTL	974	67.5	146.1	337.7
XLC	XTL	5,459	67.5	818.9	1,892.5

TABLE A-4: PEAK PERIOD AFC FLIGHT DATA MESSAGE TRAFFIC

MESSAGE TYPE	ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS			DESCRIPTION
			PEAK MSG./HR.*			
			Baseline	1983	MEAN CHAR.	
1	IFCP	ARTCCs	76	166	1,000	Short reports
	IFCP	ATCTs	76	166		
	IFCP	FSSs	22	48		
	IFCP	ARINC & Airlines	102	223		
2	IFCP	ARTCCs	4	9	30,000	Long reports
	IFCP	ATCTs	4	9		
3	ARTCCs	IFCP	88	192	500	Requests for reports
	ATCTs	IFCP	88	192		
	FSSs	IFCP	12	26		

Source: NAC WM.303G.02, Automated Flow Control, Requirements Analysis, December 30, 1980

* Collective peak-period traffic on Atlanta switch-to-Jacksonville concentrator link.

TABLE A-5: FLOW CONTROL MESSAGE CHARACTERISTICS

3. ARINC and airlines will interface NADIN at the Atlanta switch. Thus messages to those destinations will use only the Jacksonville to Atlanta link.

4. Three NADIN concentrators (New York, Chicago and Washington) receive significantly more of the messages than the other 17 CONUS concentrators. It is estimated that 11.54 percent of the Type 1 and Type 2 messages leaving the Atlanta switch are routed through each of the three "busier" concentrators and 3.85 percent are routed through each of the other seventeen (a 3-to-1 ratio). As a result, 9 x 3.85 = 34.6 percent are routed from the Atlanta switch to the Salt Lake City switch.

5. The origins of Type 3 messages are assumed uniformly distributed with respect to the 20 concentrators. Thus, 5 percent of the Type 3 messages will enter NADIN through each concentrator and 9 x 5 = 45 percent will be routed from the Salt Lake City switch to the Atlanta switch. All Type 3 messages plus the appropriate share (3.85 percent) of Type 1 and Type 2 messages will be routed from the Atlanta switch to the Jacksonville concentrator.

The results of this distribution process are shown in Table A-6.

A.3.3 FSAS Traffic

The FSAS throughput requirements have been taken from the Level IA Study (as summarized from Reference 14). In distributing these requirements to individual NADIN links, three categories of messages have been considered:

- file transfers,
- messages to and from ARO, and
- all other messages.

Thirteen types of file transfers have been identified. These are indicated in Table A-7. All thirteen are transferred from each of the two AWPs (collocated with the NADIN switches) to each associated FSDPS (one collocated with each NADIN concentrator).

BACKBONE LINK		MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
FROM	TO	MESSAGE TYPE	MSG./HR.	MEAN CHAR.	NET	GROSS
ZJX	XTL	1	603.0	1,000	1,340.0	1,651.7
		2	18.0	30,000	1,200.0	1,408.6
		3	20.5	500	22.8	29.9
					2,562.8	3,090.2
XTL	ZNY, ZAU & ZDC	1	197.1	1,000	438.0	539.9
		2	10.4	30,000	693.3	813.9
					1,131.3	1,353.8
XTL	ZJX	1	65.8	1,000	146.2	180.2
		2	3.5	30,000	233.3	273.9
		3	410.0	500	455.6	598.7
					835.1	1,052.8
XTL	Each Other Associated Concentrator	1	65.8	1,000	146.2	180.2
		2	3.5	30,000	233.3	273.9
					379.5	454.1
XTL	XLC	1	591.0	1,000	1,313.3	1,618.8
		2	31.1	30,000	2,073.3	2,433.8
					3,386.6	4,052.6
XLC	Each Associated Concentrator	1	65.8	1,000	146.2	180.2
		2	3.5	30,000	233.3	273.9
					379.5	454.1

TABLE A-6: PEAK PERIOD AFC FLOW CONTROL MESSAGE TRAFFIC (Page 1 of 2)

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BACKBONE LINK		MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
FROM	TO	MESSAGE TYPE	MSG./HR.	MEAN CHAR.	NET	GROSS
Each Concentrator Except ZJX	Associated Switch	3	20.5	500	22.8	29.9
XLC	XTL	3	184.5	500	205.0	269.4

TABLE A-6: PEAK PERIOD AFC FLOW CONTROL MESSAGE TRAFFIC (Page 2 of 2)

File Length (characters)	Transfer Frequency	Average Msg./Hr.	Peak Adjustment Factor	Peak Throughput (b/s)	
				Net	Gross
123,660	1/Hr.	1.0	1.	274.8	322.1
15,120	1/Hr.	1.0	1.	33.6	39.5
109,020*	1/8 Hrs.	.125	2.	60.6*	71.0*
54,510	1/8 Hrs.	.125	2.	30.3	35.5
95,000	1/12 Hrs.	.0833	2.	35.2	41.2
26,400*	1/12 Hrs.	.0833	2.	9.8*	11.5*
13,200	1/12 Hrs.	.0833	2.	4.9	5.7
2,000	1/12 Hrs.	.0833	2.	.7	.9
64,000*	6/Day	.25	2.	71.1*	83.4*
32,000	6/Day	.25	2.	35.6	41.7
8,970*	6/Day	.25	2.	10.0*	11.7*
4,485	6/Day	.25	2.	5.0	5.9
19,040	1/Hr.	1.0	1.	42.3	49.7
Total AWP-to-FSDPS Tranfer				613.9	719.8
Total AWP-to-AWP Transfer				151.5	177.6

* These files are also transferred between AWPs.

Source: FAA-RD-80-128, NADIN Communications Support for Flight Service Automation System, November 1980.

TABLE A-7: AWP-TO-FSDPS FILE TRANSFERS

In addition, four of the same files (identified by the Table A-7 footnote) are also transferred between the AWPs.

Unlike other message traffic which occurs essentially at random, the file transfers are scheduled. Thus, a file which is transferred once an hour will be transferred exactly once during a peak hour. A file transferred once every eight hours may or may not be transferred during a peak hour. If the file transfers could be scheduled so that approximately the same number of file characters (over a number of different files) could be transferred each hour, the average message frequency shown in Table A-7 could be used to determine peak throughput. Such an assumption would be too optimistic for this analysis. Rather, it has been conservatively assumed that the effective message frequency during the peak period is twice the average for those files scheduled for transfer less frequently than once an hour. This is indicated by the Peak Adjustment Factor in the table, and is reflected in the throughput requirements shown.

The Airport Reservation Office is assumed to interface NADIN via the Jacksonville concentrator. Thus messages from an FSDPS to ARO will be routed from the concentrator collocated with the FSDPS, to the associated switch, across the switch-to-switch link, if necessary, and then from the Atlanta switch to the Jacksonville concentrator. All messages from ARO to an FSDPS would follow the reverse route. ARO message traffic is assumed to be approximately the same for each FSDPS. Thus the data from the Level IA Study (and Reference 14) have been used for each link between a switch and concentrator (other than the Atlanta/Jacksonville link). The switch-to-switch traffic and the Atlanta/Jacksonville link traffic have been determined by the appropriate aggregation of all messages using those links.

Data for other FSAS message traffic identified in the Level IA Study have been used directly, assuming essentially the same level of traffic between each FSDPS and associated AWP. The message characteristics and resultant throughput requirements for all three categories of messages are shown in Table A-8.

A.3.4 NFDC/IS Traffic

The NFDC/IS throughput requirements considered, reflect primarily the implementation of Alternative 2 from the Communications Support Study for NFDC/IS (Reference 16). That alternative considers the use of NADIN backbone links only for (non-batch) communications between NFDC, connected to the Washington concentrator, and

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
FROM	TO	CATEGORY	MSG./HR.	MEAN CHAR.	NET	GROSS
Any NADIN Concentrator Except ZJX	Associated Switch	Files	-	-	-	-
		ARO	7	40	.6	1.9
		Other	226	54	27.1	70.9
			435	120	116.0	206.8
			24	60	3.2	7.9
			459	15	15.3	100.1
		Total	-	-	162.2	387.6
ZJX	XTL	Same as other concentrators.			162.2	387.6
		ARO	140	15	4.7	30.5
		Total	-	-	166.9	418.1
Either Switch	Any Associated Concentrator Except ZJX	Files	(See Table A.5)		613.9	719.8
		ARO	7	15	.2	1.5
		Other	1,805	322	1,291.6	1,799.9
			435	120	116.0	206.8
			24	60	3.2	7.9
			459	15	15.3	100.1
		Total	-	-	2,040.2	2,836.0

SOURCE: FAA-RD-80-128, NADIN Communications Support for Flight Service Automation System, November 1980

TABLE A-8: FSAS PEAK PERIOD MESSAGE TRAFFIC (Page 1 of 2)

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
FROM	TO	CATEGORY	MSG./HR.	MEAN CHAR.	NET	GROSS
XTL	ZJX	Same as other concentrators.			2,040.2	2,836.0
		ARO	140	40	12.4	39.1
		Total	-	-	2,052.6	2,875.1
XTL	XLC	Files	(See Table A.5)		151.5	177.6
		ARO	63	15	2.1	13.7
		Other	1,805	322	1,291.6	1,799.9
		Total	-	-	1,445.2	1,991.2
XLC	XTL	Files	(See Table A.5)		151.5	177.6
		ARO	63	40	5.6	17.6
		Other	1,805	322	1,291.6	1,799.9
		Total	-	-	1,448.7	1,995.1

SOURCE: FAA-RD-80-128, NADIN Communications Support for Flight Service Automation System, November 1980

TABLE A-8: FSAS PEAK PERIOD MESSAGE TRAFFIC (Page 2 of 2)

CNS/AIS, connected to the Atlanta switch. Characteristics of that traffic have been taken directly from the referenced study.

Subsequent to the referenced study, consideration has been given to the use of a back-up NOTAM processor in Salt Lake City. Estimates of the message traffic between CNS and the back-up processor (switch-to-switch) were included in the Level IA Study. In order to ensure a conservative estimate of switch-to-switch throughput requirements, those estimates have been included in this analysis also. Table A-9 summarizes the message characteristics and throughput requirements on the pertinent NADIN links.

A.3.5 NAS-NAS Traffic

NAS-NAS traffic characteristics have been developed on an origin-destination basis (see Section 2 of this report). Since the origins and destinations for this traffic are the NAS 9020 computers collocated and interfaced with the 20 CONUS NADIN concentrators, the traffic can be directly assigned to the specific links. Table A-10 shows the accumulated NAS-NAS traffic characteristics and throughput requirements for each NADIN link.

A.3.6 Total Throughput

The gross throughput requirements presented above for the various types of traffic are tabulated for each of the 21 NADIN links in Table A-11. That table also shows the total requirements for each direction on each link.

The line utilization (U) implied by these results is determined as:

$$U = CGT/C$$

where C = the line capacity, in bits per second,

= 9,600 b/s for links between a switch and concentrator,

= 19,200 b/s for the switch-to-switch links,

and CGT = the cumulative gross throughput on the link.

Table A-12 shows the throughput requirements and utilization for the ten busiest links.

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
FROM	TO	MSG./HR.	MEAN CHAR.	NET	GROSS
ZDC	XTL	21	48	2.2	6.3
		84	141	26.3	44.2
		636	80	113.1	239.8
				141.6	290.3
XTL	ZDC	9	694	13.9	17.7
		120	161	42.9	69.1
		636	50	70.7	193.3
				127.5	280.1
Either Switch	Other Switch	21	40	1.9	5.9
		1	225	.5	.7
		16	235	8.4	12.1
		70	120	18.7	33.3
				29.5	52.0

Source: FAA-RD-80-116, Communications Support for NFDC/IS, August 1980.

TABLE A-9: NFDC/IS PEAK PERIOD MESSAGE TRAFFIC

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
FROM	TO	MSG./HR.	MEAN CHAR.	NET	GROSS
ZTL	XTL	3,888	37.7	325.7	1064.0
ZBW	XTL	720	37.7	60.3	197.0
ZAU	XTL	3,090	37.7	258.9	845.6
ZOB	XTL	3,380	37.7	283.2	925.0
ZID	XTL	3,695	37.7	309.6	1011.2
ZJX	XTL	3,532	37.7	295.9	966.6
ZME	XTL	1,955	37.7	163.8	535.0
ZMA	XTL	2,027	37.7	169.8	554.7
ZMP	XTL	1,477	37.7	123.7	404.2
ZNY	XTL	3,948	37.7	330.8	1080.4
ZDC	XTL	3,570	37.7	299.1	977.0
XTL	XLC	2,695	37.7	225.8	737.5
ZAB	XLC	1,644	37.7	137.7	449.9
ZDV	XLC	2,255	37.7	188.9	617.1
ZFW	XLC	1,887	37.7	158.1	516.4
ZHU	XLC	1,462	37.7	122.5	400.1
ZKC	XLC	2,204	37.7	184.6	603.2
ZLA	XLC	2,700	37.7	226.2	738.9
ZOA	XLC	1,574	37.7	131.9	430.7
ZLC	XLC	1,329	37.7	111.3	363.7
ZSE	XLC	628	37.7	52.6	171.9

TABLE A-10: NAS-NAS PEAK PERIOD MESSAGE TRAFFIC (Page 1 of 2)

NADIN BACKBONE LINK		MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
FROM	TO	MSG./HR.	MEAN CHAR.	NET	GROSS
XTL	ZTL	3,328	37.7	278.8	910.8
XTL	ZBW	819	37.7	68.6	224.1
XTL	ZAU	3,415	37.7	285.1	934.6
XTL	ZOB	3,623	37.7	303.5	991.5
XTL	ZID	3,815	37.7	319.6	1044.0
XTL	ZJX	4,408	37.7	369.3	1206.3
XTL	ZME	2,501	37.7	209.5	684.4
XTL	ZMA	1,611	37.7	135.0	440.9
XTL	ZMP	1,797	37.7	150.5	491.8
XTL	ZNY	2,483	37.7	208.0	679.5
XTL	ZDC	4,438	37.7	371.8	1214.5
XLC	XTL	3,651	37.7	305.9	999.2
XLC	ZAB	1,813	37.7	151.9	496.2
XLC	ZDV	1,899	37.7	159.1	519.7
XLC	ZFW	1,949	37.7	163.3	533.4
XLC	ZHU	1,184	37.7	99.2	324.0
XLC	ZKC	1,921	37.7	160.9	525.7
XLC	ZLA	1,973	37.7	165.3	539.9
XLC	ZOA	1,810	37.7	151.6	495.3
XLC	ZLC	1,415	37.7	118.5	387.2
XLC	ZSE	763	37.7	63.9	208.8

TABLE A-10: NAS-NAS PEAK PERIOD MESSAGE TRAFFIC (Page 2 of 2)

NADIN NODES		PEAK PERIOD GROSS THROUGHPUT (B/S)											
		FROM A TO B						FROM B TO A					
A	B	NADIN I	AFC	FSAS	NFDC/IS	NAS-NAS	TOTAL	NADIN I	AFC	FSAS	NFDC/IS	NAS-NAS	TOTAL
ZTL	XTL	365	334	388	0	1,064	2,151	495	454	2,836	0	911	4,696
ZBW	XTL	365	224	388	0	197	1,174	495	454	2,836	0	224	4,009
ZAU	XTL	365	323	388	0	846	1,922	495	1,354	2,836	0	935	5,620
ZOB	XTL	365	467	388	0	925	2,145	495	454	2,836	0	992	4,777
ZID	XTL	365	462	388	0	1,011	2,226	495	454	2,836	0	1,044	4,829
ZJX	XTL	365	3,539	418	0	967	5,289	495	1,053	2,875	0	1,206	5,629
ZME	XTL	365	401	388	0	535	1,689	495	454	2,836	0	684	4,469
ZMA	XTL	365	290	388	0	555	1,598	495	454	2,836	0	440	4,225
ZMP	XTL	365	284	388	0	404	1,441	495	454	2,836	0	492	4,277
ZNY	XTL	365	334	388	0	1,080	2,167	495	1,354	2,836	0	680	5,365
ZDC	XTL	365	368	388	290	977	2,388	495	1,354	2,836	280	1,215	6,180
XTL	XLC	1,273	4,053	1,991	52	738	8,107	1,273	2,162	1,995	52	999	6,481
ZAB	XLC	365	296	388	0	450	1,499	495	454	2,836	0	496	4,281
ZDV	XLC	365	284	388	0	617	1,654	495	454	2,836	0	520	4,305
ZFW	XLC	365	301	388	0	516	1,570	495	454	2,836	0	533	4,318
ZHU	XLC	365	229	388	0	400	1,382	495	454	2,836	0	324	4,109
ZKC	XLC	365	345	388	0	603	1,701	495	454	2,836	0	526	4,311
ZLA	XLC	365	196	388	0	739	1,688	495	454	2,836	0	540	4,325
ZOA	XLC	365	190	388	0	431	1,374	495	454	2,836	0	495	4,280
ZLC	XLC	365	118	388	0	364	1,235	495	454	2,836	0	387	4,172
ZSE	XLC	365	202	388	0	172	1,127	495	454	2,836	0	209	3,994

TABLE A-11: REQUIRED THROUGHPUT FOR INDIVIDUAL NADIN LINKS

FROM	TO	GROSS THROUGHPUT (B/S)	UTILIZATION
XTL	XLC	8,107	0.42
XLC	XTL	6,481	0.34
XTL	ZDC	6,180	0.64
XTL	ZJX	5,629	0.59
XTL	ZAU	5,620	0.59
XTL	ZNY	5,365	0.56
ZJX	XTL	5,289	0.55
XTL	ZID	4,829	0.50
XTL	ZOB	4,777	0.50
XTL	ZTL	4,696	0.49

TABLE A-12: UTILIZATION OF BUSIEST NADIN LINKS

A.4 NETWORK DELAYS

Delays encountered by NAS-NAS messages on NADIN fall into three major categories:

- queueing delays for each link used,
- transmission time on each link, and
- node processing delays.

The total network delay (TD) would thus be calculated as:

$$TD = \sum_{i=1}^{n} (TQ_i + TM_i) + (n+1) \times TN$$

where TQ_i = the queueing delay on link i, in seconds,

TM_i = the NAS-NAS message transmission time on link i, in seconds,

TN = the processing time per node, in seconds, and

n = the number of NADIN backbone links involved in the transmission (2 or 3 for NAS-NAS messages).

The processing delay per node is conservatively estimated to be 50 milliseconds, i.e.:

$$TN = .05 \text{ seconds}$$

The transmission time is determined from:

$$TM_i = GL \times B/C_i$$

where C_i is the transmission rate (capacity) on link i, in bits per second,

and GL and B are the gross message length and bits per character as discussed earlier.

For the links between a switch and concentrator, C_i = 9,600 b/s. On the switch-to-switch link, although the effective capacity is 19,200 b/s, a given message will always be transmitted over a single 9,600 b/s channel. Hence, C_i = 9,600 b/s for the dual-channel link also. Thus, for NAS-NAS messages, which have a mean length of 37.7 characters:

$$TM_i \quad = \quad (37.7 + 63 + 11) \times 1.016 \times 8/9{,}600 \; = \; .09 \text{ seconds, for all links}$$

Using the above results, the network delay can be expressed as:

$$TD \quad = \quad (n \times .09) + (n + 1) \times .05 + \sum_{i=1}^{n} TQ_i$$

$$= \quad .47 + \sum_{i=1}^{n} TQ_i, \text{ if } n = 3$$

$$= \quad .33 + \sum_{i=1}^{n} TQ_i, \text{ if } n = 2$$

Determination of the queueing delays requires the consideration of several variations. Primary among these is the presence or absence of files to be transferred. Another important variation is the use of single or dual transmission channels. The procedures used to estimate the queueing delays are based on the analyses detailed in Reference 14.

A.4.1 Queueing Delays in the Absence of File Transfers

On links involving no file transfers, messages can be assumed to arrive at random. For the single-channel links, the queueing delay will be approximately:

$$TQ_i \quad = \quad TF_i \times U_i/(1-U_i)$$

where TF_i = the average transmission time, in seconds, per frame on link i,

$$= \quad GLF \times B/C_i$$

GLF = the gross length, in characters, of an average frame,

and U_i, C_i and B are the link utilization, link capacity and bits per character, as discussed earlier.

As a conservative estimate, a full frame (245 characters) is considered in estimating TF_i. Thus:

$$GLF = (245 + 11) \times 1.016 = 260 \text{ characters}$$

$$TF_i = 260 \times 8/9{,}600 = .22 \text{ seconds}$$

$$U_i = CGT_i/9{,}600$$

$$U_i/(1-U_i) = CGT_i/(9{,}600-CGT_i)$$

$$TQ_i = .22 \times CGT_i/(9{,}600-CGT_i) \text{ seconds, for the single-channel links.}$$

The above approximation assumes random (Poisson) message arrivals and a standard deviation of frame length that is equal to the average frame length (a conservative assumption). The bases for this approximation can be found in most queueing theory texts (see, for example, Reference 17, Chapter 3).

Files will be transferred in both directions on the dual-channel switch-to-switch link. Peak-period queueing delays for those links would thus be determined as discussed below.

A.4.2 Queueing Delays in the Presence of File Transfers

The relatively large file (or report) transfers introduced by FSAS and AFC traffic can create intervals of several minutes during which a link will be transmitting at essentially full capacity. The assumption of random message arrival, used above, is therefore not applicable during such intervals. These intervals will be the real peak periods for NADIN.

As recommended in the Level IA Study (and Reference 15), it is assumed that a discipline will be implemented at the NADIN switches, such that large file transfers will not unduly delay other message traffic. This has been modeled as follows:

- Consider the NADIN backbone link connecting a switch (Node A) and an associated concentrator or the other switch (Node B). For this link, Node A will effectively maintain a number of output message queues, one for each output port at Node B (plus a top priority message queue, which need not be considered here).

- The discipline at Node A will cycle through the queues for Node B, processing each queue in turn.

- If a queue (Queue I) is empty, it is instantly passed over.

- If Queue I is not empty, one frame from that queue is transmitted to Node B and processing passes to Queue I + 1. Any other message frames in Queue I must await processing in subsequent cycles.

The mean queueing delay for the first or only frame in a randomly arriving message, under such a process can be determined approximately as:

$$TQ_i = .75 \times TC_i$$

where TC_i = mean time per cycle through the queues for link i.

TC_i is determined by noting that during the file transfer interval the full capacity of the link is utilized ($U_i = 1.0$) and a relatively fixed amount of time (TF_i') is devoted in each cycle to the transfer of the file frame(s).

If U_i' is the utilization associated with the random (non-file transfer) traffic,

then $TF_i'/TC_i = 1 - U_i'$

i.e., the fraction of the cycle time devoted to file transfer is equal to the fraction of the capacity not used for random traffic.

Thus:

$$TC_i = TF_i'/(1 - U_i')$$

$$U_i' = (CGT_i - GFT_i)/C_i$$

where GFT_i = gross throughput requirement for file transfers on link i (averaged over the peak hour).

and CGT_i and C_i are the gross throughput and capacity for link i, as discussed earlier.

Combining the above expressions:

$$TQ_i = .75 \times TF_i' \times C_i/(C_i + GFT_i - CGT_i)$$

For the message traffic considered in this study, two "file transfer" queues would exist, one for the scheduled FSAS files and the other for the long (30,000 character) AFC reports. Table A-13 summarizes the throughput on each NADIN link associated with such transfers (from Tables A-6 and A-8). The totals shown in that table are the values for GFT_i in the above expression for U_i'.

Since $GFT_i = 0$ for most concentrator-to-switch links, queueing delay for those links would be determined as described in A.4.1 above. Although the Jacksonville concentrator to Atlanta switch link does involve file (large report) transfers, it is unlikely that a discipline such as described above could be implemented at the concentrators. Thus the procedures of A.4.1 would also be applicable to that link.

For the switch-to-concentrator links, both file transfer queues may contain frames simultaneously. Thus:

$$TF_i' = 2 \times TF_i = .44 \text{ seconds}$$

where TF_i = the full frame transmission time (.22 seconds), discussed earlier.

and TQ_i = $.75 \times .44 \times 9{,}600/(9{,}600 + GFT_i - CGT_i)$

$= 3{,}168./(9{,}600 + GFT_i - CGT_i)$ seconds.

Determining TF_i' for the switch-to-switch links is not as direct. Since there are two 9,600 b/s channels, a randomly arriving message can be transmitted over the second channel while a file frame is being transmitted on the first. It is convenient therefore to treat this case as if there were a single 19,200 b/s channel; i.e.:

$$C_i = 19{,}200$$

$$TF_i' = m \times 260 \times 8/19{,}200 = m \times .11$$

where m = the number of file queues used.

NADIN BACKBONE LINK		GROSS FILE TRANSFER THROUGHPUT (B/S)		
FROM	TO	FSAS	AFC	TOTAL
XTL	ZNY, ZAU & ZDC	719.8	813.9	1,534
Either Switch	Any Other Associated Concentrator	719.8	273.9	994
XTL	XLC	177.6	2,433.8	2,611
XLC	XTL	177.6	0	178
ZJX	XTL	0	1,408.6	1,409
Any Other Concentrator	Associated Switch	0	0	0

TABLE A-13: PEAK HOUR FILE TRANSFER THROUGHPUT

Thus, for the Atlanta to Salt Lake City link:

$$TQ_i = .75 \times .22 \times 19{,}200/(19{,}200 + GFT_i - CGT_i)$$

$$= 3168/(19{,}200 + GFT_i - CGT_i) \text{ seconds.}$$

For the Salt Lake City to Atlanta link:

$$TQ_i = .75 \times .11 \times 19{,}200/(19{,}200 + GFT_i - CGT_i)$$

$$= 1584/(19{,}200 + GFT_i - CGT_i) \text{ seconds}$$

A.4.3 Network Delay Summary

The above expressions have been used to determine the queueing delays for each NADIN backbone link, considering both the 1983 and 1988 throughput requirements. The 1988 requirements have been approximated as 122 percent of those for 1983. The results of these calculations are shown in Table A-14.

The queueing delays shown in Table A-14 have been used to calculate the network delays (TD), as discussed earlier. Thus, for example, NAS-NAS messages transmitted from Jacksonville to Houston will encounter (in 1988):

Node Processing Delays (4 nodes)	=	4 x .05	=	.20 seconds
Transmission Delays (3 links)	=	3 x .09	=	.27
Queueing Delays (3 links):				
ZJX to XTL			=	.45
XTL to XLC			=	.25
XLC to XHU			=	.55
Total Delay			=	1.72 seconds

NADIN NODES		QUEUING DELAYS (SECONDS)			
NODE A	NODE B	FROM A TO B		FROM B TO A	
		1983	1988	1983	1988
ZTL	XTL	.06	.08	.54	.63
ZBW	XTL	.03	.04	.48	.53
ZAU	XTL	.06	.08	.57	.69
ZOB	XTL	.06	.08	.54	.63
ZID	XTL	.07	.09	.55	.65
ZJX	XTL	.27	.45	.64	.81
ZME	XTL	.05	.06	.52	.60
ZMA	XTL	.04	.05	.50	.56
ZMP	XTL	.04	.05	.50	.56
ZNY	XTL	.06	.08	.55	.64
ZDC	XTL	.07	.09	.64	.81
XTL	XLC	.23	.25	.12	.13
ZAB	XLC	.04	.05	.50	.56
ZDV	XLC	.05	.06	.50	.56
ZFW	XLC	.04	.05	.50	.56
ZHU	XLC	.04	.05	.49	.55
ZKC	XLC	.05	.06	.50	.56
ZLA	XLC	.05	.06	.51	.58
ZOA	XLC	.04	.05	.50	.56
ZLC	XLC	.03	.04	.49	.55
ZSE	XLC	.03	.04	.48	.53

TABLE A-14: NADIN LINK PEAK PERIOD QUEUEING DELAYS FOR RANDOMLY ARRIVING MESSAGES

Table A-15 presents some of the results obtained. Specifically that table lists the nine origin/destination pairs which would experience the greatest network delays (as projected for 1988). Review of the detailed results indicates:

- Based on the 1983 throughput estimates, 34 of the 90 NAS-NAS connections (i.e., 38 percent) would experience average peak period network delays in excess of 1 second.

- Based on the 1988 throughput estimates, 57 of the 90 NAS-NAS connections (i.e., 63 percent) would experience average peak period network delays in excess of 1 second.

- The shortest average delay was found to occur for traffic from Salt Lake City to Seattle - .84 seconds for 1983, .90 seconds for 1988.

A.5 NADIN IA MODIFICATIONS

The above analysis demonstrates that NADIN, as configured under the Level IA configuration, cannot meet NAS-NAS delay constraints without some modifications. Several techniques are available for reducing the expected delays. These include:

- Using a separate dedicated channel on each link for the transmission of large files and reports;

- Modification of the NADIN priority scheme, and hence the network software, to assign NAS-NAS messages a higher priority than other ATC messages and/or to assign large files and reports a lower priority;

- Increasing the capacities of selected links, by adding one or more 9,600 b/s channels to be used for all message traffic.

NAS-NAS TRAFFIC		PEAK NETWORK DELAY (SECONDS)	
FROM	TO	1983	1988
ZJX	ZHU	1.46	1.72
ZJX	ZDC	1.24	1.59
ZHU	ZJX	1.27	1.46
ZJX	ZNY	1.15	1.42
ZJX	ZTL	1.14	1.41
ZID	ZKC	1.19	1.37
ZAU	ZKC	1.26	1.36
ZTL	ZHU	1.25	1.35
ZKC	ZAU	1.21	1.35

TABLE A-15: SELECTED NADIN NETWORK DELAYS FOR NAS-NAS TRAFFIC

The first of the above techniques would be the most expensive since it involves some software modification and the most added channels. The second would be the least expensive since it involves only software modifications. Care must be taken with that approach to insure that no ATC messages or files are unduly delayed.

For purposes of estimating the cost of Alternative 2, the third technique, increasing the capacities of selected links, has been assumed. This approach is the simplest to implement and provides the basis for a reasonably conservative cost estimate. From an analysis of the detailed delay data, it has been determined that the NAS-NAS delay constraint can be met for all NAS-NAS origin/destination pairs by adding one 9,600 b/s channel to fifteen switch-to-concentrator links. These specifically include:

- The 10 links between the Atlanta switch and all associated concentrators except the one at Boston, and

- The 5 links between the Salt Lake City switch and the concentrators at Houston, Kansas City, Denver, Fort Worth and Salt Lake City.

APPENDIX B

NADIN ENHANCEMENTS TO ACCOMMODATE PACKET SWITCHING

APPENDIX B

NADIN ENHANCEMENTS TO ACCOMMODATE PACKET SWITCHING

B.1 INTRODUCTION

B.1.1 Purpose

This appendix describes a potential enhancement to the National Airspace Data Interchange Network (NADIN) based on the implementation of a distributed architecture and the employment of state-of-the-art packet-switching technology. The application of such technology is addressed only in terms of an evolutionary first step, tailored to facilitating the incorporation of Computer B (NAS-NAS) message traffic into NADIN.

B.1.2 Background

The trend in communications support for large, dispersed, computer-based systems is toward the use of highly connected, distributed networks employing packet-switching technology. Such a network appears particularly suitable for meeting the long range requirements for Air Traffic Control (ATC) data communications. NADIN, although being implemented essentially as a centralized, message-switching network, has an architecture that can evolve into such a packet-switched network.

At the time NADIN was initially designed, packet-switching technology had not reached a state-of-the-art consistent with ATC low-risk requirements. Significant progress in packet-switching technology and applications over the past several years now makes such an approach a viable option for current FAA developments. In fact, the potential for increased capabilities at reduced costs provided by such an approach make packet switching a particularly attractive option in the present environment of tighter budgets and increasing demands on the ATC system.

The current study, analyzing communications support alternatives for the Computer B (NAS-NAS) message traffic, provides a first analytic look at the application of a distributed, packet-switched network (DPSN) for ATC communications. This analysis is not a full-scale evaluation of DPSN for all present and future ATC applications. Rather:

- it considers the introduction of packet switching as an enhancement to the NADIN architecture;

- it only considers use of the network for that message traffic to be included under the Level IA implementation of NADIN plus the NAS-NAS message traffic;

- it does not address the detailed architectural changes to best support other ATC requirements; and

- it does not address the network transition approach.

Nevertheless, the analysis (see Appendix C) demonstrates the cost-effectiveness of employing a DPSN for ATC applications.

B.1.3 Outline

The enhancements to the NADIN architecture, envisioned for the initial implementation of the DPSN concept, are presented in the next three sections. Specifically:

- Section B.2 presents a general overview of the DPSN concept.

- Section B.3 describes the NADIN IA architecture, as a basis for discussing enhancements.

- Section B.4 discusses the enhancements directly.

The final section, Section B.5, discusses other capabilities and enhancements that might be of interest for longer range considerations.

B.2 CONCEPT OVERVIEW

General references to packet-switching technology usually presume the integration of four architectural elements:

- packet switching;
- multiplexing;
- high connectivity; and
- distributed control.

Although each of these elements can be implemented independently, the manner in which they complement each other has made their combination a very desirable approach for large, computer-based data communications network designs. The DPSN addressed by this memorandum specifically includes all four elements.

The general implications of these design elements are discussed below. Their specific application for the enhancement of NADIN is presented in subsequent sections. A more complete discussion of these concepts can be found in Reference 18.

B.2.1 Packet Switching

Packet switching is a method of operating a telecommunications network in which short message units, called packets, are handled independently by the backbone network. A limit on the size of a packet is defined for the network; each message entering the network is therefore converted into one or more packets, depending on its size. In its simplest form, packet switching involves the buffering and forwarding of the individual packets by successive network nodes along the transmission path. This basic concept is also reflected in the link level ADCCP protocol used on the NADIN IA backbone links. In NADIN IA, messages are transmitted in units called frames, each containing a maximum of 245 message characters.

The major advantage of packet switching is that it facilitates the network's handling of traffic from diverse data terminals and computers operating at different speeds. A broader spectrum of advantages can be obtained by combining packet switching with multiplexing, high connectivity and distributed control.

Packet switching can be implemented in two basic ways - datagram service and virtual circuit service. Virtual circuit service, in turn, can be implemented in a number of ways. The X.25 standard protocol recommendation (Reference 19) supports all such variations.

With datagram service, each packet is handled independently by the network. At each node that receives the packet, only the next link on the packet's journey to its destination is determined. If messages are divided into two or more packets, it is possible for successive packets to be directed along different routes and to arrive at the destination out of sequence. Resolution of packet sequence must then be performed by the receiving individual, intelligent terminal or computer.

The major advantages of datagram service are that it requires no end-to-end circuit set up and it provides for more balanced use of network link capacities. Its disadvantages are the relatively high overhead in network control messages that provide the nodes the data on which to select the best next link, and the need for user sequencing of received packets.

Virtual circuit service overcomes the packet sequencing problem of datagram service by including mechanisms for packet sequencing within the network itself. Two of the more efficient techniques that have been used to accomplish this are:

- buffering and sorting of a limited number of packets from a single message at the last backbone node to handle the message; and

- establishing a fixed path over which all packets from a single message will flow in sequence.

The former approach is very similar to datagram service in terms of the handling of individual packets. It does, however, require additional network resources for buffering and sequencing, and results in added network delays. The latter approach sacrifices the assurance of balanced link usage and so may result in greater delays due to link congestion. Establishment of a fixed path, however, can reduce node processing delays, especially for longer messages and sequences of messages between two network users.

Either of the above approaches to packet sequencing can be used with either of the two major variations of virtual circuit service - virtual call and permanent virtual circuit. With virtual call service, a virtual circuit is established for the duration of a specific "call," possibly including responses to the call. With permanent virtual circuit service, the virtual circuit is established for an indefinite period. Both variations require added network overhead in order to set up and break down the virtual circuits. With permanent virtual circuits, this is done much less frequently; however, this means that buffers and other network resources will be tied up even when not in use.

As indicated above, each of the various approaches to packet switching has advantages and disadvantages. The optimal approach must be determined through analysis of message traffic characteristics, delay constraints and available resources.

B.2.2 Multiplexing

Packet switching would offer few benefits without multiplexing. Multiplexing refers to the use of one high speed (capacity) communications channel to handle (essentially simultaneously) messages received from a number of lower speed channels. Standard techniques include time-division multiplexing (TDM) and frequency-division multiplexing (FDM), whereby each incoming channel is assigned a specific portion of the outgoing channel's resources (transmission time cycle for TDM, frequency bandwidth for FDM).

For packet switching a variation of TDM called statistical multiplexing (or concentration) is generally used. Only one packet is transmitted over a backbone channel at a time; however, there are no fixed time slots. Rather, packets are interleaved, generally in the order they are received or generated (barring special priority considerations). This allows use of an output channel which has less capacity than the sum of the capacities of the input channels. Level IA NADIN uses this technique in the transmission of ADCCP frames between concentrators and switches.

B.2.3 Connectivity

A network is considered highly connected if it would take an unusually large number of simultaneous link outages to eliminate all communications paths between any two nodes. This is achieved through a network topology that includes direct links from each node to two or more other nodes.

NADIN under the Level IA configuration does not provide high connectivity. Rather, it relies on a dial back-up service in the event of link outages. The current NAS-NAS network does have a highly connected topology; however, it does not provide the mechanism for switching the messages along an alternate route. Rather, the NAS-NAS network uses redundant lines between pairs of ARTCCs to provide back-up service in the event of line outages.

In addition to its value in the event of line outages, high connectivity can also provide alternate routing capability to avoid primary paths that are congested. This routing

capability is generally used to optimize loading in packet-switched networks. Optimally, each packet could be independently routed over the path that instantaneously has the minimal end-to-end delay. Alternatively, a minimal delay path could be temporarily established for transmission of a series of packets between a given pair of nodes.

B.2.4 Distributed Control

Level IA NADIN involves centralized routing control, in that most messages are directed to one of the two switches for processing and routing. The exceptions are the locally switched (e.g., FDIO) messages which do not use the backbone links.

Completely centralized routing control for highly connected networks becomes somewhat inefficient. Generally, for such networks, switches are located at many (or all) backbone nodes and the routing control is distributed among those switches. Some centralized control is usually retained to coordinate the functioning of the otherwise independent switches.

Distributed control is made possible by the sharing of link status and utilization data. Pertinent data (e.g., packet queueing delays) are continuously collected and made available to each switching node. The nodes use these data in conjunction with a routing algorithm to update routing tables. The network overhead implied by the collection, distribution and/or accessing such data is relatively large. This is generally compensated for, however, by the increased efficiency of the resulting routes.

B.3 NADIN IA ARCHITECTURE

The enhancements to the NADIN architecture being considered to implement packet switching represent a minimum of changes - just those needed for the efficient support of NAS-NAS and Level IA NADIN message traffic. Understanding of the enhanced architecture is thus facilitated by first reviewing the Level IA architecture and then identifying the changes to that architecture.

NADIN is currently being developed as a centralized network. It includes two interconnected, centrally located, message-switch nodes. These are each connected by a star-patterned subnetwork to eleven or twelve concentrator nodes. Under the Level IA implementation the link between a switch and each associated concentrator consists of one full-duplex, voice-grade line, operating at 9,600 bits per second (b/s). The link between the

two switches consists of two such lines. The two switches, the twenty-three concentrators and the links interconnecting them make up the NADIN backbone network. The complete network can be considered to also include the various ATC data terminals and computers which use the NADIN facilities and the circuits and subnetworks by which they are linked to the backbone network.

Typically, a NADIN message is directed from the originating data terminal or computer through a concentrator to the associated switch. The switch then routes the message to its destination (terminal or computer) by way of the other switch, if necessary, and the concentrator to which the destination is linked. Variations to this typical routing include local switching at the concentrators for certain message traffic and the entry/exit at the switches for message traffic involving external systems (e.g., WMSC and International AFTN).

The NADIN concentrators are intelligent statistical multiplexors. Their major functions include:

- limited message processing, e.g., code and format conversion;
- local switching of pertinent traffic, including the collection and periodic forwarding of statistics on such traffic to the central switch;
- application of link-level protocols, including the fragmenting/reassembly of messages into/from ADCCP frames;
- buffering of messages; and
- multiplexing/demultiplexing of message frames.

Each switch consists of two major components - a front-end processor (FEP) and a message processor (DS714). The FEP is functionally and physically similar to a NADIN concentrator. It performs the actual switching functions. All links to the NADIN switch are through the FEP. The DS714 is a computer with associated peripheral equipment (e.g., tape and disk drives). Its functions include:

- message editing;
- message routing;
- message recording/recovery;
- accounting; and
- network control.

B.4 ENHANCED ARCHITECTURE

Many of the NADIN IA architectural elements are consistent (or at least not inconsistent) with requirements for a DPSN capable of also supporting NAS-NAS message traffic. In the first evolutionary step to implement packet switching, such elements should be retained. As a result, the major modifications required are:

- increased backbone node connectivity;
- addition of the packet-switching function; and
- modification or relocation of some network functions, as necessitated by the implementation of packet switching (e.g., the routing function).

The enhanced architecture is described in the following subsections in terms of:

- retained NADIN IA elements;
- connectivity;
- backbone nodes; and
- routing/switching functions.

B.4.1 Retained NADIN IA Elements

Neither the application of packet switching nor the incorporation of NAS-NAS traffic suggests any reason for relocating the NADIN backbone nodes. On the contrary, since the NADIN concentrators are to be collocated and interfaced with the NAS 9020s, the concentrator node locations are optimal for NAS-NAS support.

The requirement to provide some processing and concentration at the concentrator nodes will continue to exist under the enhanced architecture. In order to accommodate additional DPSN functions at those nodes, any one of three options could be implemented. These are:

- enhancement of the concentrators to perform the new functions (including packet switching);

- replacement of the concentrator by a new combination concentrator/packet-switch unit; or

- addition of a separate packet-switch module (PSM), retaining the concentrators and enhancing them only to the degree needed to appropriately interface with the PSMs.

The latter of the above options is suggested for the initial implementation of packet switching, since that approach would have minimal impact on the system currently being implemented. This approach has been assumed in the more detailed analyses in this study.

Although not pertinent for NAS-NAS traffic, many NADIN messages would continue to require the message processing functions provided by the DS714 and best provided at centralized locations. These would include primarily those messages which must be recorded for possible retrieval, those to or from external systems and those to or from less intelligent terminals, which require editing and routing support. Thus the DS714 message processors would be retained under the enhanced architecture. Similarly, the FEPs would be retained to serve as the front ends for the DS714s and as the gateways for external systems.

As implied by the above discussion, there would be no need to change the interfaces between the concentrators and the various data terminals and computers that use NADIN, nor between the FEPs and the external systems. Further, there would be no need to modify the basic NADIN message format.

B.4.2 Connectivity

Consideration of the conversion of NADIN into a DPSN was motivated by the NAS-NAS requirements for shorter network delays and better back-up service than would be available under the NADIN IA architecture. Higher connectivity for the NADIN nodes would be a major step in meeting both of those requirements. Provision of direct links between concentrators at many adjacent ARTCCs would reduce network (node) processing for most NAS-NAS messages. The availability of alternate routes would reduce possible congestion, thus reducing delays on individual links and, further, would provide back-up service of almost equivalent quality to the primary service, should a primary route link be out.

In order to estimate the cost of the DPSN approach, a minimal-connectivity DPSN topology has been determined (see Appendix C). The criteria used in determining that network included the following:

- All links would consist of one or more 9,600 b/s channels.
- At least two non-overlapping paths would exist between each pair of packet-switch nodes.
- The average network delay for all NADIN traffic would be less than two seconds during a busy hour.
- The average network delay for NAS-NAS messages between any pertinent pair of origin/destination nodes would be less than one second during a busy hour.
- Network costs would be minimized.

The optimal network topology determined consists of 31 links made up of 37 channels operating at 9,600 b/s. Nine of these channels are identical with ones included under the Level IA implementation. The monthly communications cost for this configuration, using the 1981 MPL tariffs, would be approximately $4,500 more than for the NADIN IA configuration. This compares with a cost of approximately $50,000 per month for the current NAS-NAS network.

B.4.3 Backbone Nodes

As suggested earlier, the NADIN IA backbone nodes would be retained under the enhanced architecture. The composition and function of the nodes would be changed, however; e.g., PSMs would be added. Under the NADIN IA architecture, there are two types of nodes:

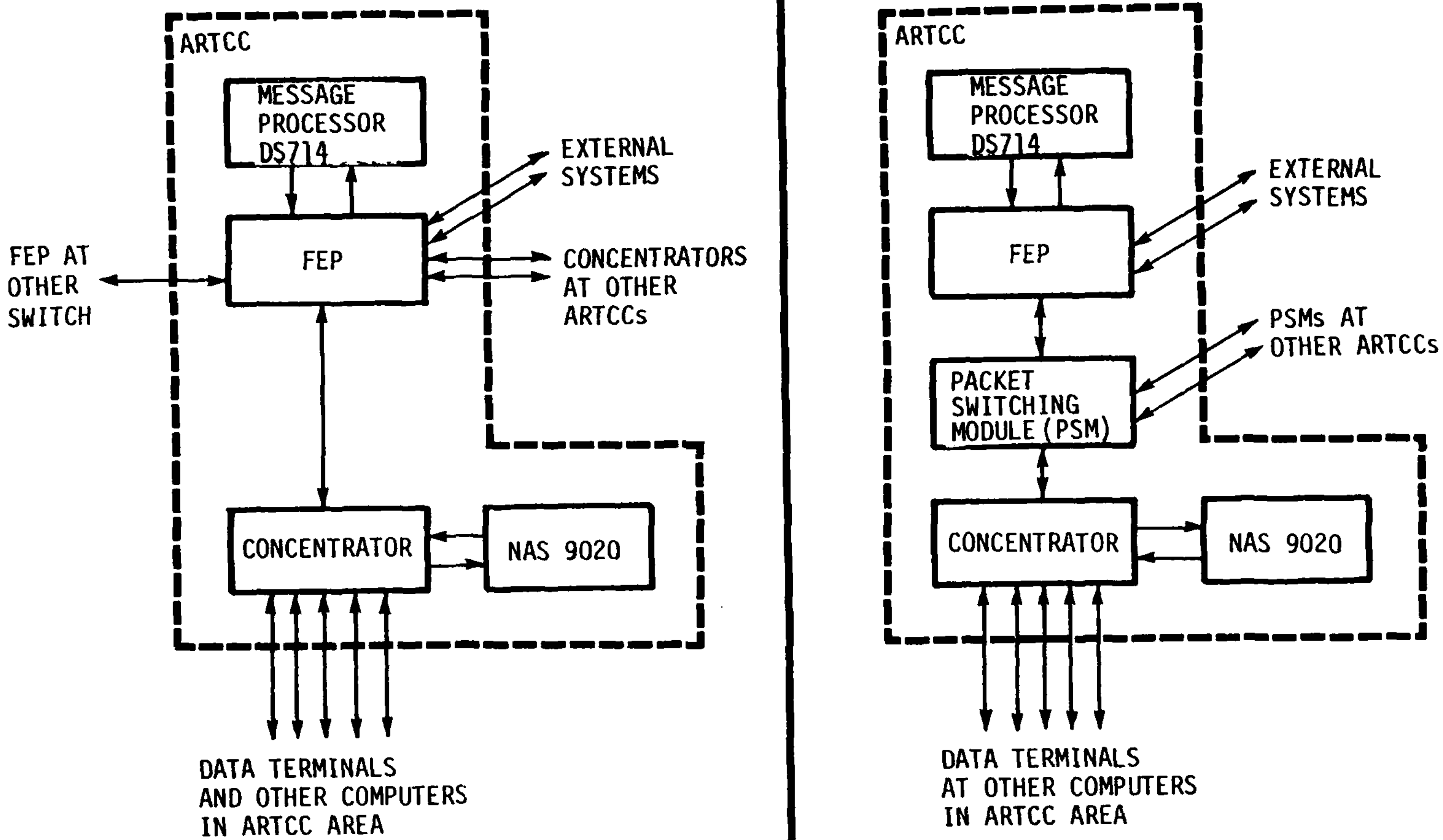
- message-switch nodes at the Atlanta and Salt Lake City ARTCCs, which also include concentrators; and
- concentrator nodes at the 18 other CONUS ARTCCs and at three off-shore ARTCCs (Anchorage, Honolulu and San Juan).

The enhanced NADIN architecture would result in three types of nodes:

- combined message-switch, packet-switch nodes at the Atlanta and Salt Lake City ARTCCs, which would also include concentrators;
- packet-switch nodes at the 18 other CONUS ARTCCs, which would also include concentrators; and
- concentrator nodes at the three off-shore ARTCCs.

The three off-shore nodes would remain essentially unchanged for this initial DPSN application. This is practical since they would not be origins or destinations for any NAS-NAS traffic, it would be unlikely that they would be selected as part of alternate routes for messages between other nodes, and they are not expected to generate much NADIN backbone traffic. Each of the off-shore concentrators would be linked directly to the PSM at a convenient packet-switch node. Those concentrators would thus be functionally modified in the same manner as the other 20 concentrators.

The modifications to the two message-switch nodes are indicated in Figure B-1. The major change is seen to be the addition of the PSM and the transfer of the major switching function from the FEP to the PSM. The FEP would continue to serve as the front end for the DS714 and as a gateway for external systems. The concentrator would continue to serve as the backbone network access point for ATC data terminals and computers.



A. NADIN IA

B. ENHANCED NADIN ARCHITECTURE

FIGURE B-1: MODIFICATION OF MESSAGE-SWITCH NODES

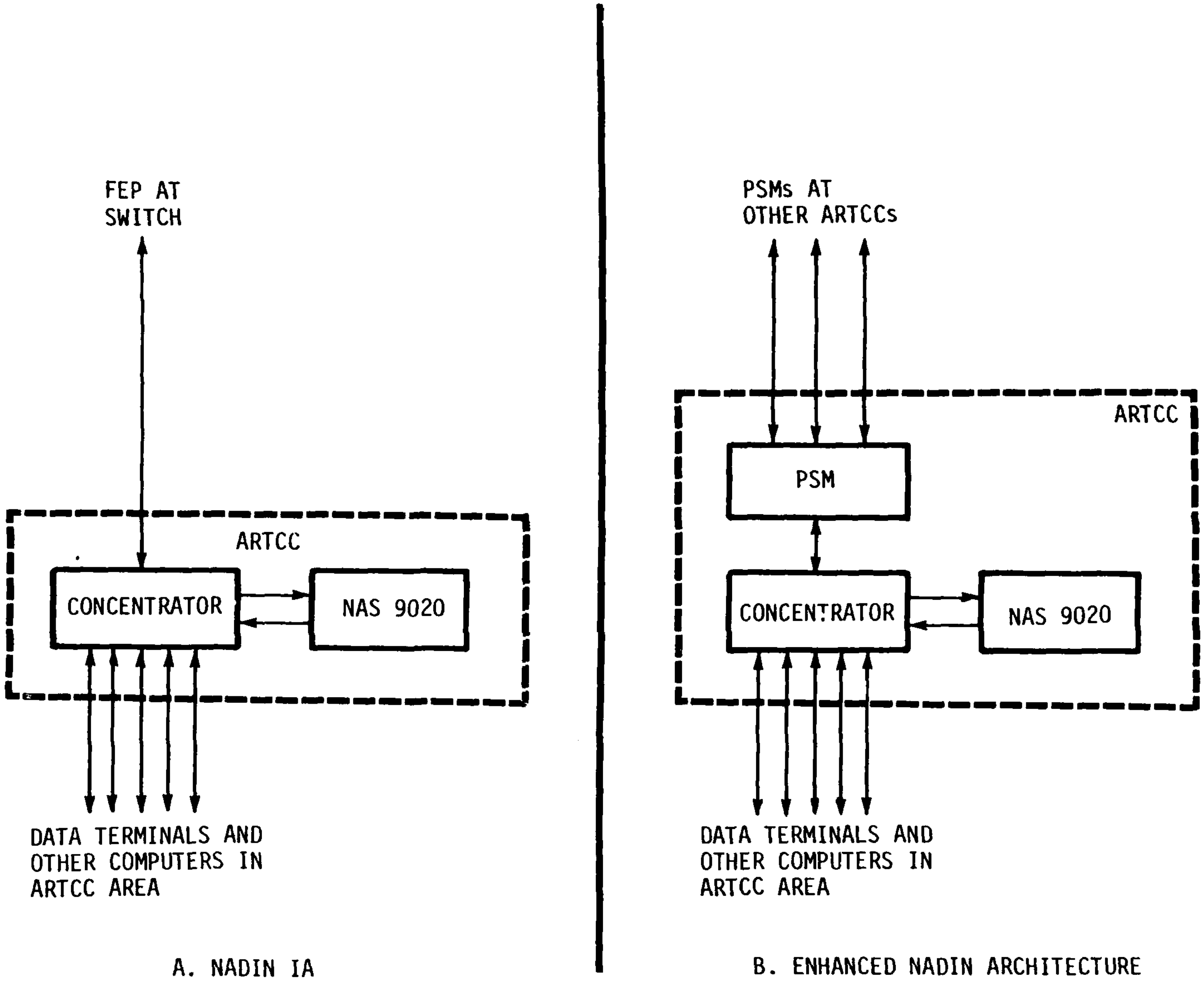


FIGURE B-2: MODIFICATION OF OTHER CONUS NODES

B.4.4.2 Function Separation

Many of the individual functions associated with routing could be performed by either the PSM or concentrator/FEP. As a general consideration, the PSM should be assigned nearly all major new functions, i.e., those not included under Level IA NADIN. This would minimize needed modifications to the concentrators and FEPs. However, the concentrators/FEPs would be responsible for functions such as message packetizing and message traffic accounting, although these functions would be somewhat changed from similar functions performed under Level IA NADIN. Further, the DS714 would perform the centralized routing control function, including the establishment and adjustment of permanent virtual circuits (if used).

All functions associated directly with packet switching would be assigned to the PSM. These would include the buffering of received messages, the determination of the appropriate next link, the maintenance of routing tables and the implementation of packet-level (level 3) protocols. Additional study would be required to determine the optimal location of functions such as the establishment of virtual calls and the association of service type to message class.

B.5 OTHER POSSIBLE ENHANCEMENTS

The enhanced NADIN architecture discussed above represents a first, minimal evolutionary step directed to the accommodation of NAS-NAS message traffic by a DPSN version of NADIN. In order to better accommodate other types of traffic, especially those that might be added to NADIN in the future, there are a number of other enhancements that might be considered. These include:

- consolidation of PSM and concentrator/FEP functions into a single hardware unit;
- conversion of the three off-shore nodes into packet-switch nodes;
- further increasing network connectivity; and
- addition of concentrator nodes.

The latter, which is the only one of the four not alluded to earlier, would involve the location of NADIN concentrators near clusters of ATC data terminals, e.g., major airports. Such concentrators could be linked directly to the PSM at the associated ARTCC. This would significantly reduce the load on the center concentrators and would most likely reduce the communications cost associated with local access to the backbone network. It is anticipated thus such an architectural extention will be analyzed as part of Task 3 under this contract.

APPENDIX C

NETWORK DESIGN FOR ALTERNATIVE 3

APPENDIX C

NETWORK DESIGN FOR ALTERNATIVE 3

C.1 PURPOSE AND SCOPE

This appendix describes the analysis performed to develop an enhanced NADIN architecture capable of satisfying the 1988 performance requirements of the NADIN Level IA traffic and the NAS-NAS traffic. It presents the data and assumptions used in the analysis, and outlines the methodology employed.

C.2 GENERAL APPROACH

Under Alternative 3, the NADIN architecture would be enhanced to provide distributed packet switching. Such a distributed architecture should, in comparison with NADIN IA, result in greater reliability and reduced delays achievable for a given cost. Such an architecture could also serve as an interim step in the expected evolution of NADIN into a packet-switched network serving all ATC message traffic.

In determining the optimal architecture of this type, the following assumptions have been used:

1. The backbone network nodes would be located at the 20 CONUS ARTCCs (and, probably, the 3 overseas ARTCCs).

2. The 20 CONUS nodes would all be packet switches with limited message processing capabilities.

3. Special message processing functions (performed at the two switches under the NADIN I and IA implementations) would be performed under Alternative 3 by message processors (switches) collocated with the Atlanta and Salt Lake City packet switches. These functions would include message recording for historical purposes and routing assistance for messages from external systems and less sophisticated terminals.

These processors would be considered as network hosts, rather than network communications nodes.

4. As under NADIN I and IA, the 20 CONUS nodes would be divided into two groups - 11 in the East group and 9 in the West. Messages requiring special processing that originate at one of the East switches would be routed to the Atlanta processor; those that originate at one of the West switches would be routed to the Salt Lake City processor.

5. Network links would consist of one or more full duplex, voice grade lines, operating at 9,600 b/s.

6. Node interconnections would be such that at least two non-overlapping routes exist between every pair of nodes.

7. The backbone links for this network would be used to transmit the same categories of traffic as specified for Alternative 2 (see Appendix A); i.e., NADIN I, AFC, NFAS, NFDC/IS and NAS-NAS.

This analysis has addressed only a generalized concept of a *distributed architecture*. As a result, it has not addressed:

- possible relocation of backbone network nodes,
- changes required to the network protocol, and
- possible changes in message priority handling.

The optimal set of links for the backbone network has been determined with the aid of GRINDER, a NAC proprietary package of interactive network design programs. The specific programs employed were those that determined costs, link flows (throughput routing) and end-to-end delays for specific network configurations, and that suggested configuration changes to meet end-to-end delay constraints. These applications required the following inputs:

- network node locations,

- throughput requirements for each origin/destination pair,

- tariffs for the pertinent communications service,

- various parameters for delay calculations, e.g., frame length, node processing time and overhead factors, and

- the delay constraint.

The special considerations associated with these inputs are discussed below.

C.3 INPUT CONSIDERATIONS

The GRINDER generalized network representation includes several features that do not directly reflect the Alternative 3 concept. These limitations and their resolutions are outlined below with reference to the major input categories.

C.3.1 Network Nodes

GRINDER generally requires the identification and location of all terminals and host computers, and the actual or potential location of communications facilities (backbone nodes). For the specific GRINDER programs used, however, it was not necessary to include the terminals and hosts. Rather it was sufficient to identify the origins and destinations of message traffic as the backbone nodes at which messages enter or leave the network, respectively. Further it was assumed that the backbone nodes would be located at the 20 CONUS ARTCCs.

C.3.2 Throughput Requirements

Throughput requirements are input to GRINDER separately for each origin/destination pair. It was thus necessary to translate the link-associated throughput specified in Appendix A into the required format. The results of that effort are presented in Section C.4 below.

The throughput translation process encountered two major areas of difficulty. First, direct specification of end-to-end throughput would not insure that pertinent messages would be routed through the message processors. Second, there would be no way of reflecting the file transfer considerations discussed in Appendix A. The former problem was resolved by treating each message to be routed through a message processor as two messages - one from the origin node to the associated processor node, the other from the processor node to the destination node. This approach affected the specification of the end-to-end delay constraint, discussed later.

The file transfer considerations outlined in Appendix A could not be reflected with GRINDER. Rather, the conservative file transfer throughput estimates were treated as representing random traffic. This approach results in delay estimates that are low on links with low utilization and high on links with high utilization. The existence of alternate routes in the network would tend to make file transfers appear more random and thus minimize any errors this approach might introduce.

C.3.3 Tariffs

TELPAK tariffs, currently applicable for government leased lines, are scheduled to be discontinued. Thus in determining the relative costs of various configurations, the MPL tariffs were used. These are discussed in Appendix D. It was further assumed that all backbone nodes were located in areas designated "Category A" under MPL tariffs.

C.3.4 Delay Parameters

Delays are calculated by GRINDER in essentially the same manner as discussed for random traffic in Appendix A. GRINDER, however, includes the node processing delay only once for each link. Thus GRINDER's calculation of end-to-end delay will always differ from that calculated as in Appendix A, by the delay associated with one node (.05 seconds). This discrepancy was easily resolved, as discussed below under Delay Constraint.

GRINDER provides for the input of net throughput requirements and multiplicative link and network overhead factors. It was convenient, however, to input the gross throughput values, which reflect multiplicative and non-multiplicative overhead factors, and to specify the overhead factors as zero. This approach assured greater consistency between the analyses for the separate alternatives.

C.3.5 Delay Constraint

GRINDER accepts as input a single end-to-end (network) delay constraint; i.e., the maximum acceptable value of end-to-end delay for the average frame. Starting from any network configuration, it will attempt to find the least-cost configuration meeting that constraint by adding, deleting and changing the multiplicity of specific links.

NADIN IA specifications require an average peak-period delay of two seconds or less. The NAS-NAS traffic requirement is more severe; the average delay for such messages must be no greater than one second. Further, this latter constraint is assumed to apply to each NAS-NAS origin/destination pair, rather than to the average NAS-NAS traffic nationwide. The selection of the appropriate delay constraint was also affected by the need to treat some (non-NAS-NAS) messages as two messages within GRINDER and the bias of .05 seconds in the GRINDER calculations, as discussed earlier.

In order to reflect all of these considerations, a two phased application of GRINDER was employed. In the first phase a distributed network paralleling the NAS-NAS network was input, and a 1-second end-to-end delay constraint was specified. GRINDER produced an "optimal" modified network with an average end-to-end delay of approximately 1 second (2 seconds for messages routed through the processors). Since the delay constraint applied to average message frames, about half of the traffic, including some NAS-NAS traffic, had GRINDER-calculated delays greater than 1 second.

In the second phase, judgement was used to modify the GRINDER-generated configuration, through the addition of links, the increasing of existing link capacities and the deletion of links (to keep down costs). At each step in this trial-and-error process, GRINDER was employed to calculate the costs and delays for the modified design. This process was continued until a design was achieved which:

- yielded a GRINDER-calculated average end-to-end delay of less than .95 seconds,

- yielded no GRINDER-calculated delay between any NAS-NAS origin/destination pairs greater than .95 seconds,

- provided at least two non-overlapping routes between each pair of backbone nodes, and

- could not be further modified to significantly reduce costs without violating one of the above conditions.

C.4 THROUGHPUT REQUIREMENTS

The throughput requirements associated with Alternative 3, although stated in different terms, are essentially the same as those for Alternative 2. The only major difference results from the consolidation of the two nodes (switch and concentrator) at Atlanta and at Salt Lake City into single nodes. Thus some traffic, e.g., transmissions between the Atlanta AWP and FSDPS, would no longer appear on backbone links and would thus be ignored.

The 1983 requirements, stated as peak-period throughput for each origin/destination node pair are presented below, separately for each traffic category and collectively over the five categories. All values shown were increased by 22 percent to reflect the 1988 requirements. The special considerations and assumptions involved in translating the data in Appendix A are also presented.

C.4.1 NADIN I Traffic

It has been assumed that all NADIN I traffic will be routed through the message processor associated with the origin node. Thus most such messages will be counted twice, once for transmission from the origin switch to the processor switch and once from the processor switch to the destination switch. If the processor switch is also the origin or destination switch, no backbone links would be used for one (or both) of the two transmissions. Only transmissions using the backbone links are considered.

In translating the NADIN I link traffic presented in Appendix A, the following additional assumptions have been used:

1. Of the traffic previously designated as "concentrator-to-switch," 73 percent is to be routed back to the originating concentrator or to other concentrators. The remaining 27 percent is destined for terminals, computers or external systems connected to the switch. This breakout is consistent with the NADIN I design data.

2. Of the 73 percent that is to be retransmitted over the backbone network, an equal amount of traffic (collectively from all concentrators) is to be forwarded to each of the 20 concentrators.

3. Any of the previously designated "switch-to-concentrator" traffic not accounted for above (i.e., not originating at one of the concentrators) is assumed to originate at a terminal, computer or external system connected to the switch.

4. All of the previously designated "switch-to-switch" traffic is to be routed to a concentrator associated with the receiving switch (as opposed to being destined for a terminal, computer or external system connected to that switch).

The results of applying the above assumptions to the data in Table A-1 (Appendix A) are shown in Table C-1. Here, and in subsequent tables and figures of this appendix, the 20 Alternative 3 nodes are designated by the symbols used previously to designate Alternative 2 concentrators (see Table A-3, Appendix A). Thus, for example, ZTL designates the Atlanta switch under Alternative 3.

C.4.2 AFC Traffic

Under Alternative 3 it has been assumed that no AFC traffic would be routed through the message processors. Rather all flight data will be destined for the Jacksonville switch and all flow control messages will originate at or be destined for the Jacksonville switch. This specifically implies that all message duplication must be accomplished before messages leave Jacksonville.

The translation of the throughput requirements under Alternative 2 (Tables A-4 and A-6, Appendix A) to requirements under Alternative 3 is relatively direct, requiring consideration only of the traffic originating or terminating at the 19 nodes other than Jacksonville. The results of this translation are shown in Table C-2, for Flight Data Messages, and Table C-3, for Flow Control Messages.

C.4.3 FSAS Traffic

Each of the three FSAS message categories, identified in Appendix A, involved distinct considerations in translating the throughput requirements. These are summarized below:

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
Any switch except ZTL & ZLC	Associated Processor Switch	769.0	120	205.0	365.3
ZTL	Each other East Switch	14.0 529.3	3,000 120	93.4 141.1 234.5	110.0 251.4 361.4
ZTL	Each West Switch	343.0	120	91.5	162.9
ZLC	Each other West Switch	14.0 467.0	3,000 120	93.4 124.5 217.9	110.0 221.8 331.8
ZLC	Each East Switch	280.7	120	74.9	133.3

TABLE C-1: NADIN I PEAK-PERIOD MESSAGE TRAFFIC

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZAB	ZJX	766	67.5	114.9	265.6
ZTL	ZJX	878	67.5	131.7	304.4
ZBW	ZJX	559	67.5	83.9	193.8
ZAU	ZJX	846	67.5	126.9	293.3
ZOB	ZJX	1,261	67.5	189.2	437.2
ZDV	ZJX	734	67.5	110.1	254.5
ZFW	ZJX	782	67.5	117.3	271.1
ZHU	ZJX	575	67.5	86.3	199.3
ZID	ZJX	1,245	67.5	186.8	431.6
ZKC	ZJX	910	67.5	136.5	315.5
ZLA	ZJX	479	67.5	71.9	166.1
ZME	ZJX	1,069	67.5	160.4	370.6
ZMA	ZJX	750	67.5	112.5	260.0
ZMP	ZJX	734	67.5	110.1	254.5
ZNY	ZJX	878	67.5	131.7	304.4
ZOA	ZJX	463	67.5	69.5	160.5
ZLC	ZJX	255	67.5	38.3	88.4
ZSE	ZJX	495	67.5	74.3	171.6
ZDC	ZJX	974	67.5	146.1	337.7

TABLE C-2: PEAK PERIOD AFC FLIGHT DATA MESSAGE TRAFFIC

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZJX	ZNY, ZAU & ZDC	197.1 10.4	1,000 30,000	438.0 693.3 1,131.3	539.9 813.9 1,353.8
ZJX	All Other Switches	65.8 3.5	1,000 30,000	146.2 233.3 379.5	180.2 273.9 454.1
Each Switch except ZJX	ZJX	20.5	500	22.8	29.9

TABLE C-3: PEAK PERIOD AFC FLOW CONTROL MESSAGE TRAFFIC

C.4.3.1 File Transfers

All file transfers originate at the AWPs, which are collocated with the processor nodes (Atlanta and Salt Lake City). Thus the previous "switch-to-concentrator" file traffic will originate at the processor nodes and be destined for the other, associated (East or West) switches. The previous "switch-to-switch" file traffic involves only AWP-to-AWP transfers; thus such traffic involves the two processor nodes as origins and destinations under Alternative 3.

C.4.3.2 ARO Messages

All ARO messages originate or terminate at Jacksonville. It is assumed that these will not be routed through the message processors. Thus, as with the AFC traffic, translation of such traffic requires only the consideration of ARO traffic originating or terminating at the other 19 nodes.

C.4.3.3 Other Messages

All other FSAS messages are assumed to be routed through the message processors. Most of these remain in the same region (East or West) as the originating node. The Alternative 2 "concentrator-to-switch" and "switch-to-concentrator" traffic directly identifies the origin/destination traffic for such messages.

Some of these messages are, however, exchanged between East and West nodes. These are included in the twenty-four 60-character messages per hour and 24 (of the 459) 15-character messages per hour transmitted from each FSDPS (located at the ARTCC) to the 19 other FSDPSs (located at the 19 other ARTCCs). It is assumed that the destinations for such messages are equally distributed over the 19 other nodes. Thus there will be (11 x 24) 264 messages of each of the two types transmitted to the Atlanta message processor. Of these, (10/19) 53 percent will be retransmitted to East nodes and (9/19) 47 percent to West nodes. Thus each of the eleven East nodes will receive (.53/11) 4.8 percent, and each of the nine West nodes will receive (.47/9) 5.3 percent. Similarly, of the (9 x 24) 216 messages of each of the two types transmitted to the Salt Lake City processor, (8/19) 42 percent will be retransmitted to West nodes and (11/19) 58 percent to East nodes, with (.42/9) 4.7 percent going to each West node and (.58/11) 5.3 percent to each East node.

In translating the link traffic into origin/destination traffic, it was thus necessary to subtract from the Alternative 2 "switch-to-concentrator" traffic those messages originating in the other section of the U.S. For example, the "other" traffic from the East processor (ZTL) to any other East node would be the "switch-to-concentrator" traffic for Alternative 2, reduced by the cross-country messages; i.e., (216 x .053) 11.4 less messages per hour of each the 60- and 15-character messages. These cross-country messages would now originate at the West processor (ZLC).

C.4.3.4 Summary of FSAS Traffic

Table C-4 presents the results of translating the Alternative 2 FSAS throughput requirements (Table A-8, Appendix A) to origin/destination format. As with previously discussed traffic categories, messages not transmitted over backbone links are ignored.

C.4.4 NFDC/IS Traffic

All NFDC/IS traffic considered involves transmission between Washington and Atlanta or between Atlanta and Salt Lake City. Thus the Alternative 2 requirements (Table A-9, Appendix A) translate directly into Alternative 3 requirements. These are presented in Table C-5.

C.4.5 NAS-NAS Traffic

NAS-NAS throughput requirements were previously developed in an origin/destination format. Since such messages need not be routed through the processor nodes, the original data have been directly applied for Alternative 3 analysis. These are presented in Table C-6.

C.4.6 Total Throughput Requirements

The requirements identified above have been accumulated for each pertinent origin/destination pair in Tables C-7 and C-8. Table C-7 presents all traffic with origin or destination at one of the three busiest nodes - Atlanta, Salt Lake City and Jacksonville. This includes all of the requirements except some of the NAS-NAS traffic. The remaining requirements are presented in Table C-8.

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
		CATEGORY	MSG./HR.	MEAN CHAR.	NET	GROSS
Any Switch except ZTL ZLC & ZJX	Associated Processor Node	Other	226	54	27.1	70.9
			435	120	116.0	206.8
			24	60	3.2	7.9
			459	15	15.3	100.1
		TOTAL			161.6	385.7
ZJX	Any Other Switch except ZTL	ARO	7	15	.2	1.5
ZJX	ZTL	ARO	7	15	.2	1.5
		Other	(See above)		161.6	385.7
		TOTAL			161.8	387.2
ZTL	Any Other East Switch except ZJX	Files	(See Table A-5, Appendix A)		613.9	719.8
		Other	1,805	322	1,291.6	1,799.9
			435	120	116.0	206.8
			12.6	60	1.7	4.1
			447.6	15	14.9	97.6
		TOTAL			2,038.1	2,828.2

TABLE C-4: FSAS PEAK PERIOD MESSAGE TRAFFIC (Page 1 of 3)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
		CATEGORY	MSG./HR.	MEAN CHAR.	NET	GROSS
ZLC	Any East Switch except ZTL & ZJX	Other	11.4	60	1.5	3.7
			11.4	15	.4	2.5
		TOTAL			1.9	6.2
Any Switch except ZTL, ZLC & ZJX	ZJX	ARO	7.0	40	.6	1.9
ZTL	ZJX	Files	(See Table A-5, Appendix A)		613.9	719.8
		ARO	7.0	40	.6	1.9
		Other	1,805.0	322	1,291.6	1,799.9
			435.0	120	116.0	206.8
			12.6	60	1.7	4.1
			447.6	15	14.9	97.6
		TOTAL			2,038.7	2,830.1
ZLC	ZJX	ARO	7.0	40	.6	1.9
		Other	11.4	60	1.5	3.7
			11.4	15	.4	2.5
		TOTAL			2.5	8.1

TABLE C-4: FSAS PEAK PERIOD MESSAGE TRAFFIC (Page 2 of 3)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS			PEAK THROUGHPUT (B/S)	
		CATEGORY	MSG./HR.	MEAN CHAR.	NET	GROSS
ZLC	Any Other West Switch	Files	(See Table A-5, Appendix A)		613.9	719.8
		Other	1,805.0	322	1,291.6	1,799.9
			435.0	120	116.0	206.8
			10.1	60	1.3	3.3
			445.4	15	14.8	97.1
		TOTAL			2,037.6	2,826.9
ZTL	Any West Switch except ZLC	Other	13.9	60	1.9	4.6
			13.9	15	.5	3.0
		TOTAL			2.4	7.6
ZTL	ZLC	Files	(See Table A-5, Appendix A)		151.5	177.6
		Other	1,805.0	322	1,291.6	1,799.9
			13.9	60	1.9	4.6
			13.9	15	.5	3.0
		TOTAL			1,445.5	1,985.1
ZLC	ZTL	Files	(See Table A-5, Appendix A)		151.5	177.6
		Other	1,805.0	322	1,291.6	1,799.9
			11.4	60	1.5	3.7
			11.4	15	.4	2.5
		TOTAL			1,445.0	1,983.7

TABLE C-4: FSAS PEAK PERIOD MESSAGE TRAFFIC (Page 3 of 3)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZDC	ZTL	21	48	2.2	6.3
		84	141	26.3	44.2
		636	80	113.1	239.8
				141.6	290.3
ZTL	ZDC	9	694	13.9	17.7
		120	161	42.9	69.1
		636	50	70.7	193.3
				127.5	280.1
Either Processor Switch	Other Processor Switch	21	40	1.9	5.9
		1	225	.5	.7
		16	235	8.4	12.1
		70	120	18.7	33.3
				29.5	52.0

TABLE C-5: NFDC/IS PEAK PERIOD MESSAGE TRAFFIC

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZAB	ZDV	193	37.7	16.2	52.8
	ZFW	513	37.7	43.0	140.4
	ZKC	402	37.7	33.7	110.0
	ZLA	536	37.7	44.9	146.7
ZTL	ZHU	110	37.7	9.2	30.1
	ZID	598	37.7	50.1	163.7
	ZJX	1,535	37.7	128.6	420.1
	ZME	853	37.7	71.5	233.4
	ZDC	792	37.7	66.4	216.7
ZBW	ZOB	54	37.7	4.5	14.8
	ZNY	666	37.7	55.8	182.3
ZAU	ZOB	1,103	37.7	92.4	301.9
	ZID	736	37.7	61.7	201.4
	ZKC	363	37.7	30.4	99.1
	ZMP	889	37.7	74.5	243.3
ZOB	ZBW	54	37.7	4.5	14.8
	ZAU	1,026	37.7	86.0	280.8
	ZID	934	37.7	78.2	255.6
	ZMP	16	37.7	1.3	4.4
	ZNY	544	37.7	45.6	148.9
	ZDC	806	37.7	67.5	220.6
ZDV	ZAB	259	37.7	21.7	70.9
	ZKC	149	37.7	12.5	40.8
	ZLA	508	37.7	42.6	139.0
	ZMP	644	37.7	54.0	176.2
	ZLC	695	37.7	58.2	190.2

TABLE C-6: PEAK PERIOD NAS-NAS MESSAGE TRAFFIC (Page 1 of 4)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZFW	ZAB	407	37.7	34.1	111.4
	ZHU	666	37.7	55.8	182.3
	ZKC	243	37.7	20.4	66.5
	ZME	571	37.7	47.8	156.3
ZHU	ZTL	225	37.7	18.9	61.6
	ZFW	783	37.7	65.6	214.3
	ZJX	211	37.7	17.7	57.7
	ZME	236	37.7	19.8	64.6
	ZMA	7	37.7	.6	1.9
ZID	ZTL	659	37.7	55.2	180.3
	ZAU	1,015	37.7	85.0	277.8
	ZOB	844	37.7	70.7	231.0
	ZKC	304	37.7	25.5	83.2
	ZME	409	37.7	34.3	111.9
	ZDC	464	37.7	38.9	127.0
ZJX	ZTL	1,213	37.7	101.6	332.0
	ZHU	167	37.7	14.0	45.7
	ZMA	1,492	37.7	125.0	408.3
	ZNY	7	37.7	.6	1.9
	ZDC	653	37.7	54.7	178.7
ZKC	ZAB	162	37.7	13.6	44.3
	ZAU	625	37.7	52.4	171.0
	ZDV	155	37.7	13.0	42.4
	ZFW	180	37.7	15.1	49.3
	ZID	452	37.7	37.9	123.7
	ZME	432	37.7	36.2	118.2
	ZMP	198	37.7	16.6	54.2

TABLE C-6: PEAK PERIOD NAS-NAS MESSAGE TRAFFIC (Page 2 of 4)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZLA	ZAB	985	37.7	82.5	269.6
	ZDV	497	37.7	41.6	136.0
	ZOA	1,094	37.7	91.7	299.4
	ZLC	124	37.7	10.4	33.9
ZME	ZTL	585	37.7	49.0	160.1
	ZFW	473	37.7	39.6	129.4
	ZHU	234	37.7	19.6	64.0
	ZID	337	37.7	28.2	92.2
	ZKC	326	37.7	27.3	89.2
ZMA	ZHU	7	37.7	.6	1.9
	ZJX	1,908	37.7	159.8	522.2
	ZNY	112	37.7	9.4	30.7
ZMP	ZAU	749	37.7	62.7	205.0
	ZOB	16	37.7	1.3	4.4
	ZDV	527	37.7	44.2	144.2
	ZKC	135	37.7	11.3	36.9
	ZLC	50	37.7	4.2	13.7
ZNY	ZBW	765	37.7	64.1	209.4
	ZOB	1,341	37.7	112.3	367.0
	ZJX	7	37.7	.6	1.9
	ZMA	112	37.7	9.4	30.7
	ZDC	1,723	37.7	144.3	471.5
ZOA	ZLA	731	37.7	61.2	200.0
	ZLC	337	37.7	28.2	92.2
	ZSE	506	37.7	42.4	138.5

TABLE C-6: PEAK PERIOD NAS-NAS MESSAGE TRAFFIC (Page 3 of 4)

ORIGIN	DESTINATION	MESSAGE CHARACTERISTICS		PEAK THROUGHPUT (B/S)	
		MSG./HR.	MEAN CHAR.	NET	GROSS
ZLC	ZDV	527	37.7	44.2	144.2
	ZLA	198	37.7	16.6	54.2
	ZMP	50	37.7	4.2	13.7
	ZOA	297	37.7	24.9	81.3
	ZSE	257	37.7	21.5	70.3
ZSE	ZOA	419	37.7	35.1	114.7
	ZLC	209	37.7	17.5	57.2
ZDC	ZTL	646	37.7	54.1	176.8
	ZOB	265	37.7	22.2	72.5
	ZID	758	37.7	63.5	207.4
	ZJX	747	37.7	62.6	204.4
	ZNY	1,154	37.7	96.7	315.8

TABLE C-6: PEAK PERIOD NAS-NAS MESSAGE TRAFFIC (Page 4 of 4)

NODE A	CUMULATIVE PEAK THROUGHPUT REQUIREMENTS (B/S) FROM:					
	A to ZTL	A to ZLC	A to ZJX	ZTL to A	ZLC to A	ZJX to A
ZTL	-	2,200	3,946	-	2,169*	1,539*
ZBW	751	0	226	3,190	140	456
ZAU	751	0	325	3,190	140	1,355
ZOB	751	0	469	3,190	140	456
ZID	931	0	463	3,353	140	456
ZJX	1,539	456	-	3,946*	260*	-
ZME	911	0	402	3,423	140	456
ZMA	751	0	814	3,190	140	864
ZMP	751	14	286	3,190	153	456
ZNY	751	0	338	3,190	140	1,357
ZDC	1,218	0	574	3,687	140	1,534
ZAB	0	751	297	171	3,159	456
ZDV	0	941	286	171	3,303	456
ZFW	0	751	303	171	3,159	456
ZHU	62	751	289	201	3,159	501
ZKC	0	751	347	171	3,159	456
ZLA	0	785	198	171	3,213	456
ZOA	0	843	192	171	3,240	456
ZLC	2,169	-	260	2,200*	-	456*
ZSE	0	808	203	171	3,229	456

* These six requirements are duplicates of those shown in the first three columns for the same origin/destinations.

TABLE C-7: CUMULATIVE PEAK PERIOD MESSAGE TRAFFIC FOR BUSIEST NODES

NODE A	NODE B	CUMULATIVE PEAK THROUGHPUT REQUIREMENTS (B/S) FROM:	
		A to B	B to A
ZBW	ZOB	15	15
	ZNY	182	209
ZAU	ZOB	302	281
	ZID	201	278
	ZMP	243	205
	ZKC	99	171
ZOB	ZID	256	231
	ZMP	4	4
	ZNY	149	367
	ZDC	221	73
ZID	ZME	112	92
	ZDC	127	207
	ZKC	83	124
ZME	ZFW	129	156
	ZHU	64	65
	ZKC	89	118
ZMA	ZNY	31	31
	ZHU	2	2
ZMP	ZDV	144	176
	ZKC	37	54
ZNY	ZDC	472	316
ZAB	ZDV	53	71
	ZFW	140	111
	ZKC	110	44
	ZLA	147	270
ZDV	ZKC	41	42
	ZLA	139	136
ZFW	ZHU	182	214
	ZKC	67	49
ZLA	ZOA	299	200
ZOA	ZSE	139	115

TABLE C-8: CUMULATIVE PEAK PERIOD MESSAGE TRAFFIC FOR OTHER ORIGIN/DESTINATION PAIRS

C.5 OPTIMAL CONFIGURATION

The optimal configuration determined for the Alternative 3 network concept is shown in Figure C-1. This configuration interconnects the 20 nodes with 31 links, six requiring two 9,600 b/s lines, the remainder requiring single 9,600 b/s lines.

The optimized routing of all 1988 traffic suggested by GRINDER results in link delays (ignoring all node processing delays) shown in Table C-9. The end-to-end delays for all 90 NAS-NAS origin/destination pairs have been computed. The 16 origin/destination pairs with the greatest delays are shown in Table C-10 (including all node processing delays).

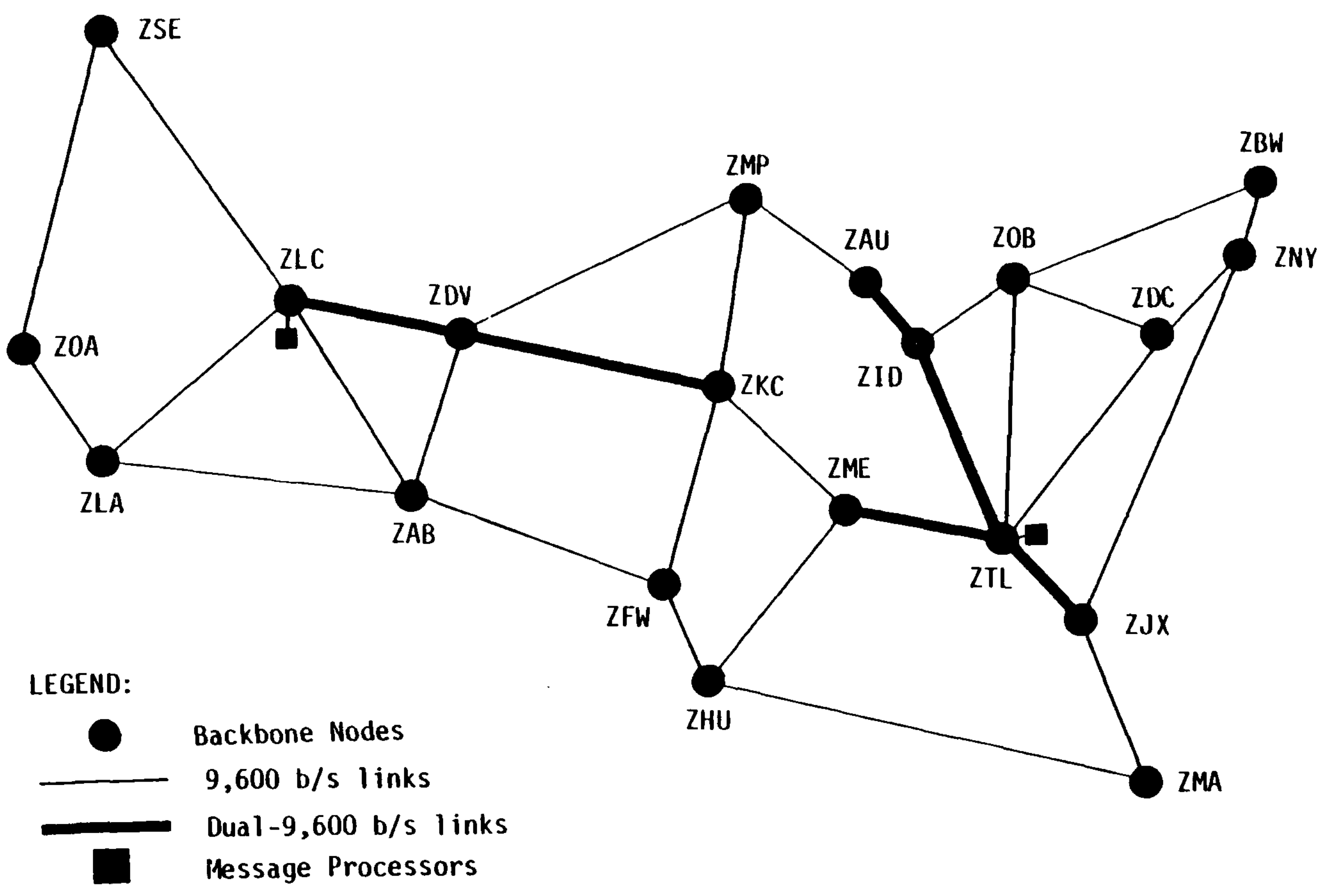


FIGURE C-1: OPTIMAL ALTERNATIVE 3 CONFIGURATION

LINK NODES		LINK DELAY (SEC.) FROM:	
A	B	A to B	B to A
ZSE	ZOA	.14	.11
ZSE	ZLC	.14	.43
ZOA	ZLA	.12	.2[illegible]
ZLA	ZLC	.15	.77
ZLA	ZAB	.17	.18
ZLC	ZAB	.85	.18
ZLC*	ZDV*	.48	.12
ZDV	ZAB	.16	.15
ZDV	ZMP	.14	.11
ZDV*	ZKC*	.19	.12
ZAB	ZFW	.41	.24
ZKC	ZMP	.14	.10
ZKC	ZFW	.15	.11
ZMP	ZAU	.18	.24
ZAU*	ZID*	.11	.16
ZKC	ZME	.38	.55
ZFW	ZHU	.27	.26
ZHU	ZME	.11	.25
ZID	ZOB	.16	.12
ZID*	ZTL*	.11	.36
ZME*	ZTL*	.12	.33
ZHU	ZMA	.20	.17
ZTL	ZOB	.54	.17
ZTL	ZDC	.61	.18
ZTL*	ZJX*	.37	.19
ZOB	ZBW	.22	.13
ZOB	ZDC	.12	.11
ZDC	ZNY	.21	.21
ZNY	ZBW	.15	.12
ZJX	ZNY	.48	.13
ZJX	ZMA	.42	.21

* Indicates dual - 9,600 b/s links.

TABLE C-9: ALTERNATIVE 3 LINK DELAYS

ORIGIN	DESTINATION	END-TO-END DELAY (SEC.)
ZLC	ZLA	.87
ZJX	ZDC	.84
ZMA	ZNY	.84
ZLC	ZMP	.77
ZTL	ZHU	.74
ZJX	ZHU	.73
ZOB	ZMP	.72
ZLC	ZOA	.72
ZID	ZKC	.71
ZTL	ZDC	.71
ZNY	ZMA	.70
ZME	ZFW	.67
ZMP	ZOB	.65
ZME	ZKC	.65
ZME	ZID	.63
ZKC	ZID	.63

TABLE C-10: MAXIMUM DELAYS FOR NAS-NAS TRAFFIC

APPENDIX D

COST ANALYSIS METHODOLOGY AND DATA

APPENDIX D

COST ANALYSIS METHODOLOGY AND DATA

D.1 PURPOSE AND SCOPE

This appendix presents the general methodology used to estimate the cost of the various alternatives for supporting NAS-NAS communications. The methodology has been designed to provide results that can be directly compared, despite the many unique considerations pertinent to individual alternatives. This appendix also presents the common data (parameter values) used to implement the methodology.

D.2 COMPARABILITY

The intent of the methodology is to produce for each alternative a single cost estimate that can be directly compared with the cost estimates for all of the other alternatives. In analyzing the various alternatives for supporting NAS-NAS communications, achieving comparable costs requires careful attention to three areas of complexity:

1. the aggregation of one-time and recurring costs;

2. the treatment of costs for systems that currently exist (or would be procured regardless of the alternative selected), but would be eliminated by one or more of the alternatives; and

3. the treatment of costs for excess NADIN communications capacity, available before or after the incorporation of the NAS-NAS services.

The manner in which these three areas have been handled essentially defines the cost methodology employed. Each is discussed separately below.

D.2.1 Life-Cycle Costs

One-time costs refer to expenditures for items such as hardware purchase, software development and systems installation. Such items are generally considered to occur and be paid for when the system is implemented or modified. If the new or modified system is expected to have a long life, some of these items will reoccur; for example, worn-out equipment would have to be replaced by newly purchased equipment.

Recurring costs refer to expenditures for such items as equipment leasing and system maintenance. Such items occur on a regular or (frequent) as-needed basis. For cost analysis they are considered to be paid for in fixed amounts (ignoring inflation) at regular time intervals (e.g., once a month).

Because of the different time factors involved, one-time and recurring costs cannot be directly added. This is generally handled by defining the system's lifetime and then including each cost item as often as it is expected to occur over one life-cycle. For this analysis a lifetime of 10 years (120 months) is assumed.

Another important difference between one-time and recurring costs is that a dollar spent today effectively costs more than one spent next year (ignoring inflation). This is so because a dollar spent today either must be borrowed, implying interest costs, or, if already available, cannot be invested, implying lost interest payments. This difference is generally resolved by calculating the present value of recurring costs (and of one-time costs that occur at a later time). The present value can be thought of as the amount of money that would have to be invested at the start in order that the combined principal and interest would exactly pay all the future costs, when due, over the life-cycle of the system. Such costs could be added directly to the initial one-time costs.

Standard models exist for estimating present values of future costs. Because of the limited lifetime of the systems being considered, all one-time costs are assumed to be expended only in 1983 (Subsection D.2.2, below, includes discussion of pre-1983 costs). The 1983 present value of the recurring costs can be calculated using:

$$PV = RC \times (1 - (1+D)^{-m})/D$$

where

PV = the present value, in dollars,

RC = the recurring costs, in dollars per month,

	m	=	the system lifetime, in months,
and	D	=	the effective cost of money, on a monthly basis.

If inflation is ignored, D would be the monthly interest (or discount) rate. If inflation is to be considered, D would be determined as:

$$D = 1 - (1+I)/(1+F)$$

where

	I	=	the monthly interest rate,
and	F	=	the monthly inflation rate.

For this analysis D is taken to be .008 per month (.10 per year) and m is taken as 120 months. Thus:

$$PV = RC \times 77.0$$

D.2.2 Existing Systems

It is assumed for this analysis that, regardless of which alternative for NAS-NAS communications support is implemented, the NAS-NAS Network would be operated through the beginning of 1983, and that NADIN Level IA would be implemented by 1983. Thus any costs associated with those systems prior to 1983 would be the same for all alternatives, and thus need not be considered in determining comparative costs.

The NAS-NAS Network would be retained in some form only under Alternatives 1 and 4. Thus all costs associated with the continued operation of that network (as modified, under Alternatives 4) must be included only in analyzing those two alternatives.

NADIN, on the other hand, would continue to be operated under all five alternatives, including in particular Alternative 1. It is convenient, therefore, to consider the cost of continuing to operate the NADIN Level IA implementation as a common cost for all alternatives, and thus to (generally) ignore that cost in the analysis. Thus, for example, Alternative 2 costs need include only the one-time and recurring costs associated with increases in link capacities. This approach cannot, however, be directly applied to

Alternative 3, since the network architecture would be significantly modified. In order to be consistent, the total cost associated with the Alternative 3 modifications and operation must be determined. Then, in order that the cost be comparable to that for the other alternatives, it must be reduced by the cost of continuing to operate NADIN under the Level IA implementation.

D.2.3 Excess Capacity

In order to insure a robust communications system, links are designed with capacities in excess of those required. Thus, for example, under Alternative 2 some of the NADIN IA links would be able to absorb the NAS-NAS traffic without an increase in capacity. Further, for those links that require an increase, capacity would be added in increments of 9,600 b/s, even though this may be well in excess of that required. This approach is generally practical, since the only significant cost difference between a 2,400 b/s and 9,600 b/s line is the cost of the modems required to interface the lines with the communications node equipment.

With an evolving system such as NADIN, it is very likely that the excess capacity would ultimately be consumed in servicing other FAA requirements, just as the NAS-NAS traffic could consume some or all the excess link capacity provided under the Level IA implementation. Two basic approaches would be generally applicable for considering the costs associated with excess NADIN link capacities. These are:

1. Marginal Costs - i.e, consider the full cost associated with increasing link capacity and consider any previously excess capacity as free.

2. Pro Rated Costs - i.e., assume that all capacity available on a link would ultimately be used (regardless of NAS-NAS support alternative implemented). Then assign as a cost to NAS-NAS support only a pro rata share for the capacity expected to be used, be that on a previously existing line or a line to be added.

For this analysis approach 1, marginal costing, has been adopted.

D.3 TARIFFS

A significant element in the costs for all five alternatives are the charges by commercial carriers for providing leased line service. For this analysis it is assumed that the Multi-Schedule Private Line (MPL) tariffs apply to both the NAS-NAS Network and the NADIN backbone network. Further, it is convenient to assume that all backbone nodes (the 20 ARTCCs) are located in areas designated "Category A" under those tariffs.

The MPL tariffs include four major categories of charges. These are:

1. Station Terminal Charges, including a one-time installation charge of approximately \$57 per drop (i.e., \$114 per point-to-point channel), and a recurring cost of \$26.30 per drop per month;

2. Fixed Charges of \$51.72 per channel per month;

3. Interexchange Mileage Charges, shown in Table D-1;

4. Channel Conditioning Charges, including an installation charge of approximately \$171 per drop, and a recurring cost of approximately \$15.50 per drop per month.

D.4 OTHER COST CONSIDERATIONS

Most of the other cost considerations are pertinent only to the individual alternatives. Those that are of more general concern are indicated below:

1. Modems required at each end of 9,600 b/s lines cost approximately \$8,500 apiece.

2. The only significant cost associated with channels between a collocated NADIN switch and concentrator is the cost of modems or other interface adaptors. Such equipment will generally be much less expensive than modems required for the long distance leased lines. For this analysis, however, two \$8,500 modems are assumed to be required for each such channel also.

3. Software development will cost approximately \$150 per instruction.

MILES	COST/MILE/MONTH
0 - 15	$1.89
16 - 25	1.58
26 - 100	1.18
100 - 1,000	.69
over 1,000	.42

Notes:

1. Rates shown are based on MPL tariffs for channels between two Category A locations.

2. Example calculations - 250 mile channel:

	15	miles	@	1.89 =	$28.35
	10	miles	@	1.58 =	15.80
	75	miles	@	1.18 =	88.50
	150	miles	@	.69 =	103.50
TOTAL	250	miles		=	$236.15

TABLE D-1: INTEREXCHANGE MILEAGE RATES

APPENDIX E

LIST OF REFERENCES

APPENDIX E

LIST OF REFERENCES

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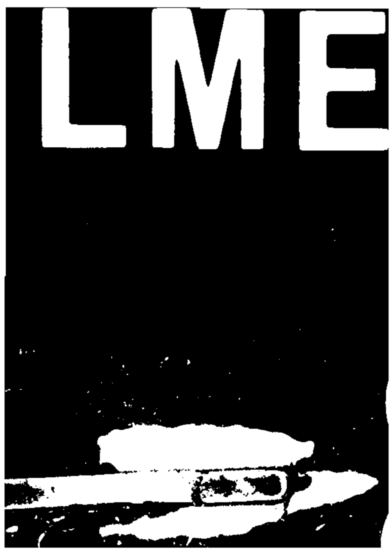
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